GUIDE TO INTERMEDIATE PRACTICAL BOTANY

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PREFACE.

This little **Guide to Intermediate Practical Botany** is the outcome of 10 years experience with Indian students, and 8 years of development and re-arrangement of an original six-page laboratory outline. Students begin their Intermediate work with little or no background of practical knowledge of, or interest in plants. The present content and arrangement of the course in practical Botany has been found to meet the needs of such students.

The Guide will cover the requirements of the former Intermediate Practical Botany Syllabus of the University of Allahabad; the requirements of the new Board of Intermediate Education; and it is hoped may be found useful in other Provinces as well.

More work is outlined than the average student will find time to complete. The teacher will have to make a selection of work, according to the time allotted to Botany and the material available for study. He should so plan his work that the later parts of the course can be covered, else the continuity of the study will be broken, and some of the most valuable conclusions omitted. Students repeating the course will find sufficient new material to keep them occupied.

The material included in these studies is drawn from the common stock of Botany, and therefore no specific acknowledgements can be made. PROFESSOR K. RANGACHARI'S MANUAL OF BOTANY FOR INDIAN SCHOOLS 2ND EDITION, is the textbook used in Ewing Christian College, and some of the experiments are based on this book. The aim has been to develop a balanced presentation of the more fundamental facts of Botany in clear simple language. Definitions and technical terms are reduced to a minimum. The student is expected to prepare much of his own material for study, perform many of the experiments, observe plant life in the field, and as far as possible draw his own conclusions from his studies, experiments, and observations. In this way the knowledge he gains will be in a real sense his own, and will not easily be forgotten.

It has been a common practice for our students to make notes, comments, and illustrations on the backs of the sheets of duplicated notes supplied to them. Acting on this suggestion, alternate pages of the Guide have been left blank. It is intended that the student shall use these pages for sketches to illustrate the text opposite. The sketches should be as full as possible, and may be taken from any source—lectures, reference books, and drawings made in the laboratory. When completed in this way the Guide becomes practically a textbook, with the added value of being built up largely out of the student's own efforts. The blank pages are *not* intended to take the place of the laboratory drawing book, which should be quite separate.

It has been the constant effort to present the fundamental facts of Botany in such a manner as to appeal to the natural curiosity of youth, and to awaken and cultivate an increasing interest in and love for nature Only a small proportion of Intermediate students will proceed to more advanced studies in Botany. Much of what they learn in the Intermediate course should be therefore what the average person of average tastes and training will find interesting and helpful in after life. At this stage of education the effort should be to develop men, not scientists. The book is intended to combine a suitable preparation for the inevitable examinations, and a development of intelligent interest in the things of nature that makes for the cultured citizen.

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ALLAHABAD, 1922.

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INTRODUCTION.

IMPORTANCE OF BOTANY.—Botany is the study of plants. It includes the study of all plants, living or dead, present or past, plant products—everything connected with plants or their activities. All animals, including man, depend on plants for their food, either directly or indirectly. Botany is one of the foundation stones of modern scientific agriculture. Botany may be studied because of its application to the life and needs of man; or from purely scientific interest.

LABORATORY WORK.—We may learn of plants by studying books, and by studying the plants themselves. The purpose of laboratory work is to enable the student to gain a knowledge of the nature and work of plants by the actual study of plants. Therefore a large part of our instruction will be in the laboratory. In addition to work in the laboratory, there will be a number of trips to study plants as they grow outside, in our own and other gardens, and wild. There will be many experiments to determine what plants do and how they do it.

In all this work the student will make careful records of his observations, in the form of notes and drawings. He should strive to improve his powers of observation and develop his interest in plants by observing and studying them whenever he has opportunity.

MATERIALS NEEDED.—The following materials will be needed for the course: loose-leaf laboratory note book with drawing and note paper; a HH or HHH drawing pencil; coloured pencils; good soft rubber; dissecting set; section razor.

DRAWINGS.—The purpose of drawings is to make a brief but accurate record of what you learn about plant structure by your own efforts. Three types of figures are asked for: **diagrams**, showing nothing more than the general arrangement and relation of parts; **sketches**, showing actual shape, and something of the structure; and **finished drawings**, as accurate in outline and detail as you can make them.

Make fine clean-cut lines; avoid shading; **name all parts of each figure** carefully and accurately, and write the **complete name** of each drawing beneath it. Do not crowd the drawings on the page. Draw on one side only of the paper, so that the drawings will appear in the right hand side of the book when open. Remember that you cannot make a good drawing until you understand thoroughly the thing you are drawing.

NOTES.—For much of the work careful accurate drawings will be sufficient. The results of experiments, and observations made on field trips will be recorded

in the form of notes. These notes will be as much a part of the laboratory note book as the drawings, and must be made with the same care. They should be written as soon as possible after the work has been completed. Notes may be patterned after Chemistry notes, and should be kept on notepaper in the proper place in the note book.

PLAN OF THE COURSE.—The course extends through two years. The first twelve laboratory periods will be spent in getting acquainted in a general way with plants, and the work will be rather simple. After this we shall begin the study of the **Intermediate** syllabus, and the work will be of more advanced grade.

PRELIMINARY STUDY OF PLANTS.

The work of this Section will be based on **Rangachari's "Botany for Secondary Schools in India"** (Macmillan & Co: Madras, Bombay, Calcutta, and London) A portion of this little book must be read before coming to the laboratory each time, or the work cannot be done quickly and easily. All the chapter and page references in the Preliminary study refer to this book.

1. Parts of the plant.

READ Chapter 2.

We shall first of all become familiar with the parts of a plant. Almost any plant might be used for this purpose, but we shall choose one that is small and simple, to make the task of drawing easier.

STUDY the plant provided (*Cleome viscosa*, *Tribulus terrestris*, or *Scoparia dulcis**) and observe the following parts:

ROOTS, growing downward into the soil.
STEM, growing upward into the air, and bearing along its sides—
LEAVES, and
FLOWERS and FRUITS.

ROOTS.—The main root growing straight down from the stem into the soil is the **tap root**; the branches are **lateral roots**. Growth in length occurs only at the ends of the roots.

STEM.—Note that the leaves are quite regularly arranged along the sides of the stem and its branches. The point where a leaf is attached to the stem is

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* Plants (and animals) are given two kinds of names. People everywhere recognize differences between various plants, and give them VERNACULAR NAMES, as ám or mango, gehún or wheat, múlí or radish, gerúí or wheat rust. Such names often cause confusion because inaccurately used, and they mean nothing in other languages. SCIENTIFIC NAMES, on the other hand, are understood all over the world, and are the same in all languages. The scientific name of each plant (and animal) is made up two parts: a GENUS NAME (always spelled with a capital letter), followed by a SPECIES NAME; thus *Mangifera indica* (ám, mango,) *Triticum vulgare* (gehún, wheat), *Raphanus sativus* (múlí, radish), *Puccinia graminis* (gerúí, wheat rust).

called a **node**, and the space between two nodes is an **internode**. At the end of the main stem and each branch is a **terminal bud** composed of a growing point and young leaves. **Branches** arise from **axillary buds** at the nodes in the angle between the leaf and the stem.

LEAF.—The leaf is composed of a broad flat green portion, **blade**, borne on a stalk, **petiole**. In many plants the blade is composed of a number of separate parts, **leaflets**; such a leaf is said to be **compound**. In many kinds of plants there is a pair of small blade-like **stipules** at the base of the petiole.

FLOWER AND FRUIT. Flowers devolop from **flower buds**, and are produced after the plant has reached maturity. Flowers are for the purpose of sexual reproduction. A flower is borne on a special branch, **pedicel**. A complete flower consists of the following four sets of organs, attached to the **thalamus** or **receptacle** at the end of the pedicel :

(*a*) SEPALS, the green outer parts, collectively called **calyx**.

(*b*) PETALS, the next set often brightly colored, collectively called **corolla**.

(*c*) STAMENS, the so-called "male organs", consisting of a slender stalk, **filament**, bearing an enlarged portion, **anther**, containing a fine yellow dust, **pollen**.

(*d*) CARPELS, the central, so-called "female organs", consisting of an enlarged base, **ovary**, containing **ovules**, or young seeds; and a stalk, **style**, bearing a sticky knob, **stigma**, at the upper end.

It is very common for these four sets of organs to grow together in various ways (Chapter 9 may be consulted here). The ovaries, whether separate or joined together, develop into a **fruit**, while the ovules inside become **seeds**.

MAKE THE FOLLOWING SKETCHES: the entire plant to show as many of the above parts as you can; a single leaf; a flower enlarged; a single stamen enlarged; and a single carpel (or group of united carpels) enlarged. Label all parts carefully, and write the name of each drawing beneath it.

2. Structure of the Plant.

3. Function of the Parts of Plant.

Each part of the plant has its special work or **function** to perform. The structure of each part is specially adapted for the performing of its special function. We shall find it most convenient to study structure and function together.

READ FOR STRUCTURE, pages 29-34, 24-27, and 42-47.

READ FOR FUNCTION, Chapters 13 and 14. Chapters 15 should be read some time before the first terminal examination.

Structure usually is studied under the heads "root, stem, and leaves," but we shall take it up, as in Zoology, under the heads :

1. Water-absorbing system.
2. Vascular system.
3. Protection system.
4. Transpiration system.
5. Carbon-assimilation system.
6. Excretory system.
7. Supporting system.

and 8. Reproductive system.

This division makes it easier to study function at the same time.

1. THE WATER-ABSORBING SYSTEM. Water will not soak into a living plant as into a piece of dry wood; it must be definitely absorbed or taken up by special organs. The water-absorbing organs are a layer of fine **root hairs** near the tip of each little root. When a plant is pulled out of the earth the root hairs are torn off and remain in the soil. They can be seen quite clearly on seedling plants grown on moist filter paper. Observe the root hairs on seedlings of *Brassica juncea* (rai).

SKETCH a young root showing root hairs.

Look at a bit of soil under the demonstration microscope and see that it is made up of minute particles of rock. Compare with sand.

OSMOSIS EXPERIMENT (p 96). Put some sugar (chíní) in a thistle tube and partly fill the bowl with water, coloured red with eosin, taking care that none of the water runs out through the stem. Tie a piece of wet goat's bladder tightly across the mouth of the bowl, and place bowl downward in a vessel of tap water. Support the thistle tube in some way, and mark the height to which the colored sugar solution rises in the stem. Look at the experiment occasionally and observe what takes place. WRITE COMPLETE NOTES.

The process is known as **osmosis**—the passage of water through a membrane from a less concentrated to a more concentrated solution. Each root hair is really a tiny tube that grows in among the soil particles and acts as an osmosis apparatus, absorbing water (with small quantities of soil salts dissolved in it) from their surface.

EXPERIMENTS TO SHOW THE IMPORTANCE OF THE ROOTS as water-absorbing organs.

Pull a plant out of the ground and lay it on the laboratory table. What happens to it after a time ? Why ?

Pull up another plant and immediately place the roots in a vessel of water. What happens to this plant ? Why ?

Examine a plant that has been pulled up and placed in water two days ago. How does it appear now? Why?

Since roots absorb water by means of their root hairs, these experiments show how necessary root hairs are to the life of the plant. WRITE COMPLETE NOTES.

2. VASCULAR SYSTEM.—After water is absorbed by the roots it must be carried to other parts of the plant. Also food materials must be carried from place to place in the plant. This carrying is done by a system of water tubes, **xylem**, and food tubes, **phloem**, extending through all parts of the plant.

Cut across an internode of a stem of the plant provided (almost any plant with a soft stem will do) and observe the ring of slightly different coloured structures lying near the surface. Cut lengthwise and see that they extend up and down through the stem. These structures are **vascular bundles**, composed of a set of xylem tubes on the side towards the centre of the stem, and phloem on the outside. The large green area in the centre of the stem is **pith**, and the thin layer outside the ring of vascular bundles is **cortex**.

SKETCH a t. s. (transverse section) of the stem to show the above features.

The vascular bundles may be seen in the leaf blades, forming a net-work of fine lines. The vascular bundles of the roots are essentially like those of the stem.

EXPERIMENTS TO SHOW THAT THE VASCULAR SYSTEM CARRIES WATER.—Cut off some delicate thin leaves and place them on the laboratory table. Why do they wilt (become soft and lose their shape)?

Cut off an entire stem with its leaves and lay it on the laboratory table. What happens? Why?

Cut off a plant of *Impatiens balsam* (gul menhdi) and immediately put the cut end into water. Now what happens? Why does the plant not wilt?

Cut off another similar plant (bearing white flowers if possible) and place the cut end immediately in water coloured red with eosin (p. 97). Observe the movement of the water upward through the stem; and that finally the flowers become tinged with red. What does this experiment show?

Cut across the stem of the plant in eosin water and observe what part is coloured red, *i. e.*, what part carried the water.

POTOMETER EXPERIMENT.—(p. 99). Observe a potometer experiment, and watch the movement of the bubble of air in the horizontal tube. What does the movement of the bubble indicate? What does this experiment demonstrate?

WRITE COMPLETE NOTES on all these experiments.

3. PROTECTING SYSTEM.—The entire surface of the plant—roots, stem, leaves, and flowers—is covered by a thin "skin," the **epidermis**. The epidermis

is waterproof, to prevent the plant from drying up, and is tough, to protect the more delicate tissues lying below it. It also keeps out disease-producing organisms. There is an immense number of very minute openings, **stomas** (or **stomata**) in the epidermis, through which oxygen and carbon dioxide pass into the plant, and waste substances pass out. The epidermis can be observed most easily in the leaf, but the stomas are too small to be seen without a microscope.

Tear a leaf and observe the transparent surface layer showing at the edges of the tear; this is the epidermis.

4. TRANSPIRATION SYSTEM.—The large amount of water taken in by the roots must get out of the plant in some way. Most of it is lost by the leaves, from which it evaporates through the stomas into the air.

There is a constant stream of water, **transpiration current**, passing upward through the roots, stem, and out of the leaves.

EXPERIMENTS TO DEMONSTRATE TRANSPIRATION.—(p. 98) Partly fill a vessel with water and cover with a glass plate with a hole in the centre. Cut off a branch with leaves, push through the hole, and tightly seal in position with soft wax. Then invert another glass over the branch, and set in a sunny place. Observe what happens. Where does the moisture come from that collects inside the upper glass ?

WRITE COMPLETE NOTES.

Select two large leaves of *Ficus bengalensis* (bargad). Cover the entire surface of one with a thin layer of vaseline, and hang both in the laboratory by a string. Observe the next laboratory period. What has happened ? Explain.

5 CARBON-ASSIMILATION SYSTEM.—Observe that the leaves and younger parts of the plant are green, while the old stems, roots, and most of the flower parts are not. This green colour is due to a green substance, **chlorophyll.**

EXTRACTION OF CHLOROPHYLL.—Grind some soft leaves to a paste in a mortar and then extract with a little (95%) alcohol. Observe that the alcohol dissolves most of the colour out of the leaves and becomes dark green. WRITE NOTES.

Plants differ from animals in that they are able to make their own food, from simple inorganic substances. They make their food out of CO_2 and H_2O by means of chlorophyll in the presence of light; the process is called **Carbon-assimilation** or **photosynthesis.** Because leaves contain more chlorophyll than other parts of the plant, and are specially formed for photosynthesis, they are usually spoken of as the **organs of carbon-assimilation.** We shall leave most of the study of photosynthesis till later ; it will be sufficient now to understand that plants make their own food by means of chlorophyll in the presence of light, out of H_2O taken in by the roots, and CO_2 taken in

from the air. To allow CO_2 to reach all parts of the green interior, the leaf contains a fine network of **air spaces**, opening to the outside through the stomas.

EXPERIMENT TO DEMONSTRATE AIR SPACES IN THE LEAF.—Seal the petiole of a leaf into the stopper of a bottle containing water, and connect with an aspirator, as shown in Fig. 113. Exhaust the air from the bottle and note the bubbles of air coming from the end of the petiole. Explain. WRITE COMPLETE NOTES.

EXPERIMENT TO DEMONSTRATE THAT CHLOROPHYLL IS FORMED ONLY IN LIGHT.—Observe the colour of seedings grown in darkness. Place these seedlings in the light and observe the next laboratory period. What change has taken place? Explain.

TEST FOR STARCH —The first product of photosynthesis is a kind of sugar, but this is soon changed into starch (máṛ), which can easily be tested for. Put a little dilute iodine solution on a cut surface of a tuber of *Solanum tuberosum* (álú), and note the blue colour that appears. The álú contains starch, and the blue colour with iodine is a test for starch.

TEST FOR STARCH IN A LEAF.—Boil a soft green leaf in water in a test-tube, extract the chlorophyll with alcohol, then treat with iodine. What is the result? Explain.

EXPERIMENT TO SHOW THAT PHOTOSYNTHESIS TAKES PLACE ONLY IN LIGHT.—Place a plant in total darkness for two days, to allow all of the starch to be carried away from the leaves. Then test a leaf for starch. With what result? Is chlorophyll by itself able to make starch?

Now place the same plant in sunlight for an hour or two, and test another leaf. What is the result? What does this experiment demonstrate? WRITE COMPLETE NOTES.

6. EXCRETORY SYSTEM —Animals have special organs for throwing waste materials out of the body, but plants have no such excretory system. Solid waste substances simply remain in the plant.

7. SUPPORTING SYSTEM.—It will be easily understood that as a plant becomes large, a great deal of strength is needed to hold it up. This strength is supplied mainly by the xylem. As the plant grows, the xylem increases in amount, and forms a solid cylinder of **wood**, with the small pith remaining in the centre. Only a small portion of the wood actually is water-carrying; most of it is formed only for the purpose of supporting the plant. Wood is what we make use of when we use trees for building material, lumber, and other purposes.

Examine a t. s. of a branch of *Bombax malabaricum* (semal) and observe the thick ring of wood. You should be able to see some of the larger water tubes also. Make a **sketch** of what you find.

Make a **list of uses of wood.**

8. THE REPRODUCTIVE SYSTEM is found in the flowers. We shall study it later.

4. Common plants of the plains.

READ chapters 19 and 20, although most of these chapters will not be easily understood till later in the course.

There are nearly 1000 different species of flowering plants native to the Upper Gangetic Plain; and there are many others that have been brought in from other places for various purposes. The object of this study is to become familiar with as many as possible of the common Plains plants, whether wild or cultivated. We shall study these plants by groups. Under each group or heading **write out** in your note book the various details that are asked for. When this is completed you will know a goodly number of the plants of the Plains.

1. TEN COMMON TREES OF THE PLAINS.—

    Scientific name; vernacular name.

    General appearance of the tree.

    Time of leaf fall, and of putting out of new leaves.

    Time of flowering and fruiting.

    Uses of various parts of the tree.

    What is the original home of the tree?

2. TEN PLANTS OF THE PLAINS THAT YOU THINK ARE MOST USEFUL.—

    Scientific name ; vernacular name.

    Characters by which each may be recognized.

    When planted, and when ready for use ?

    When used? How used ?

    Value of the products last year (or some recent year) ?

3. TEN CULTIVATED ANNUAL PLANTS.—

    Scientific name; vernacular name.

    Original home ?

    When and how cultivated ?

    How used ?

    Why is each cultivated ?

4. FIVE INTRODUCED GARDEN VEGETABLES.—

Scientific name; vernacular name.

Original home ?

When and how cultivated ?

How used ?

5. TEN WILD PLANTS OF GRAZING LANDS. –

Scientific name; vernacular name.

General characters of each.

For what is each valuable ?

6. FIVE COMMON WEEDS OF CULTIVATED FIELDS.—

Scientific name; vernacular name

General appearance

How long does each live ?

How is it spread ?

Why is it so hard to destroy ?

7. FIVE COMMON CULTIVATED FLOWERING PLANTS.—

Scientific name; vernacular name.

Original home ?

General characters.

How propagated ?

How used ?

5. Pollination.

READ Chapter 10.

POLLINATION is the transfer of pollen from the anther to the stigma. This pollen may come from the anthers of the same flower (**self pollination**), or from another flower on the same plant (**close pollination**), or from another plant (**cross pollination**). Pollination must be carefully distinguished from fertilization, which is the completion of the sexual process, after the pollen has been transferred.

When a pollen grain reaches the sticky stigma, it is held fast and begins to grow. It produces a long tube, **pollen tube**, which grows down through the style to the ovary, where it fertilizes a single ovule. By this fertilization process a new plant is produced in the ovule, which then begins to develop into a seed. Seeds are produced only by fertilization.

METHODS OF POLLEN TRANSFER.—There are four principal methods of pollen transfer: by animals, wind, gravity, and water.

POLLINATION BY ANIMALS.—By far the largest number of flowering plants depend on some kind of animal (mainly insects) for their pollination. The mutual dependence of flowering plants and insects is one of the most remarkable facts in nature.

Observe plants with conspicuous flowers on a bright day and note the insect visitors. How many kinds of insects can you observe visiting flowers? What do they do when they come to the flower? Does the same insect visit all kinds of flowers? If not, what differences can you note? What does the insect take from the flower? Does the insect visit the flower to pollinate it? Try to determine whether all flowers are likely to receive sufficient pollen; remember that it takes a single pollen grain to fertilize a single ovule.

CHARACTERS OF INSECT POLLINATED FLOWERS.—Observe the size and number of anthers; size and prominence of the stigma; position of the flowers; conspicuousness of the flowers. State the main characters of insect pollinated flowers.

POLLINATION BY WIND.—A large number of flowering plants usually regarded as primitive are pollinated by wind. Examine wind pollinated plants, such as *Triticum vulgare* (gehún), or *Ricinus communis* (rendí), or any palm. Note that the pollen is light and dry, and blows about very easily with the wind.

CHARACTERS OF WIND POLLINATED FLOWERS.—Observe whether the flowers are conspicuously coloured; the position of the flowers; the size and number of anthers (*i e.,* the amount of pollen); and the prominence of the stigma. State the main characters of wind pollinated flowers.

POLLINATION BY GRAVITY.—There is a number of flowers which pollinate themselves—the pollen merely drops from the anthers on to the stigma, usually in the same flower. It may occur in grasses during rainy weather, when the flowers do not open properly.

POLLINATION BY WATER.—A few water plants are pollinated by means of water. The stamen-bearing flowers in some are always produced below the surface, and when mature, break off and rise to the surface, where they float about and come into contact with the stigmas of carpel-bearing flowers.

WRITE FULL NOTES on pollination. Describe carefully the pollination of five wind-pollinated plants; of ten insect-pollinated plants.

MAKE A LIST of as many kinds of insect pollinators as you can observe, and show the particular types of flowers they are fitted to pollinate.

WRITE OUT the main characters of wind-pollinated flowers; of insect-pollinated flowers.

6. Seeds and Fruits.

READ Chapters 11 and 3.

Seeds are ovules that have developed after being fertilized.

STRUCTURE OF A SEED.—A seed consist of:

(*a*) EMBRYO, a little plant produced by the sexual process. It has a stem, root, terminal bud, and one or two leaves (**cotyledons**).

(*b*) FOOD MATERIAL, provided by parent plant for the embryo when it begins to grow. This food usually is starch, and is stored either around the embryo (when it is called **endosperm**) or in the cotyledons.

(*c*) SEED COATS —tough hard protective coverings, derived from the outer parts of the ovule.

Examine soaked seeds of *Cicer arietinum* (chaná), *Ricinus communis* (rendí), and *Zea mays* (makái), and find the above parts. Make the following **sketches** of each seed: surface view; split down the centre; and the embryo separated from the rest of the seed.

PURPOSE OF SEEDS—Seeds have a number of purposes:—

(*a*) To give rise to sexually-produced plants, in which the characters of two parent plants are combined.

(*b*) To enable the plant to be transported long distances safely.

(*c*) To enable the plant to remain alive during unfavourable conditions that would kill the parent plant. The embryo in a ripe seed is in a dormant condition, and can withstand great extremes of heat, cold, drought, moisture, and other hard conditions. Dry seeds may remain alive many years. Annual plants remain alive from one year to the next only by means of their seeds.

Understand clearly how seeds are fitted to serve these purposes.

USE MAN MAKES OF SEEDS.—Much of the food of man is seeds. Why is this? What is it in seeds that makes them so important as food? What are the principal seeds used as foods? In what other ways does man make use of seeds? **Write a paragraph** on "The use of seeds as food."

HOW FRUITS ARE PRODUCED.—In most plants the fruit is nothing more than a developed ovary. When the ovules are fertilized and begin to develop into seeds, the ovary also is stimulated to further growth.

Examine any available plant and trace the gradual development of the ovary into the fruit. Cut across the fruit provided and distinguish the ovary and seeds. **Sketch**.

In a number of plants other parts develop along with the ovary and become part of the fruit; for example, sepals (in shihtút), receptacle (in stawberry), and even the whole group of flowers (in sháhtút, kaṭhal, anannás).

PURPOSE OF FRUITS.—Fruit serve to protect the young seeds while they are developing, and to aid in scattering the seeds when they are ripe. Because the main function of fruits is to scatter the seed, we shall study the various kinds of fruits under that heading.

USE MAN MAKES OF FRUITS.—For the purpose of scattering their seeds some fruits ripen soft and fleshy, and are edible They form an important part of the food of man. **Make a list** of fruits used by man as food in the United Provinces. Make a list of fruits used in other ways by man.

7. Seed Dispersal; Competition; Survival.

You probably know that the seeds of plants are scattered naturally; the process of seed scattering is called **seed dispersal**. We shall now study why it is necessary for seeds to be scattered; the results of dispersal; and the ways in which they are scattered.

NUMBER OF SEEDS PRODUCED BY PLANTS. Estimate the number of seeds produced in a year by a single plant of *Pisum sativum* (baṛá maṭar), *Triticum vulgare* (gehúṉ), *Achyranthes aspera*, *Chenopodium album* (bathúá), *Dalbergia sissoo* (shísham), *Ficus bengalensis* (bargad). Or you may substitute any other plants you wish for these.

NEED FOR SEED DISPERSAL.—What would happen if all the seeds produced by plants should fall directly beneath it and germinate there? How many seedling per square foot would there be each year beneath the big bargad tree on the compound? It should be clear that even if other conditions were favourable (which they would not be) there would be entirely too many plants in one place if all seeds fell under the parent plant. So scattering is necessary; and the seeds of all plants are scattered more or less by some means. In this way the new plants may find a better place to grow; bare soils are occupied; and species gradually spread over a wide area.

WRITE A PARAGRAPH on "The need for seed dispersal."

COMPETITION BETWEEN PLANTS OF DIFFERENT SPECIES With all plants producing and scattering large numbers of seeds, a given area must receive great numbers of seed of many different kinds. If all these seeds germinate, the number of plants will be far greater than can live on the area, and most of them must die. So from year to year the number of plants on a given area remains about the same, in spite of the large nnmber of seeds that fall on it. This struggle between plants for space, light, and water and other substances from the soil is known as **competition**.

Examine several plots a foot square in various places, and **make a list** of the number and kinds of mature plants found on them ; also the number and kinds of seedlings. WRITE COMPLETES NOTES.

Bring in specimens of soil from various places, and put them in flat shallow vessels. Water carefully. Observe from time to time the number and kinds of plants that come up from seeds that were in the soil. WRITE COMPLETE NOTES.

It may be interesting to consider that the farmer prevents (*or should prevent*) competition in his fields by first destroying the wild plants, then scattering his seeds thinly, and finally by destroying all other plants as they appear. This gives the cultivated plants a chance to attain their fullest development.

METHODS OF SEED DISPERSAL.—Seeds are scattered in two principal ways (I and II) :

I. By means of their fruits ;

1. The fruits ripen fleshy and are eaten by animals, when

(*a*) the seeds pass through the digestive tract uninjured : *Ficus bengalensis* (bargad), or

(*b*) the seeds are discarded : *Mangifera indica* (ám), or

2. The fruits ripen dry and do not open at maturity, but

(*a*) have some kind of hooks or spines to catch in the hair of passing animals : *Xanthium strumarium* (chhoṭá dhatúrá), or

(*b*) have broad wings : *Holoptelea integrifolia* (páprí), or tufts of hairs : Compositae, by means of which they sail about in the wind, or

(*c*) are corky, and float on water : *Cocos nucifera* (náriyal), or

3. The fruits ripen dry, and open at maturity

(*a*) Explosively : *Impatiens balsam* (gul mendhí), or

(*b*) gently, in such a way that the seeds are thrown out when the wind blows : *Argemone mexicana* (katáya) or

(*c*) gently, and

II. The seeds scatter themselves after they fall out : because

1. They are small, smooth, and light, and blow about with the dust : *Chenopodium album* (bathúá), or

2. They have wings : *Moringa pterygosperma* (sainjná), or tufts of hairs : *Calotropis procera* (ák), and sail away in the wind, or

3. They are carried away by various animals for food, and some are lost.

The above list includes only the more inportant methods of seed dispersal. It will serve to emphasize that the main function of the fruit is to secure the scattering of the seeds. You will find many plants which appear not to have any definite means for scattering their seeds, and probably their seeds are not well scattered.

SKETCH as many of the above examples (or others) as you have time for, showing clearly the means for securing seed dispersal.

8. Growth forms—Modifications for Displaying the Leaves.

READ Chapters 5 and 6.

Most plants have erect stems that are strong enough to support themselves ; these stems hold up the leaves, and serve as a water and food transportation system. Most roots grow downward into the soil, taking up water and dissolved salts from the soil, and holding the plant in an upright position. Most leaves are thin and serve as the principal organs of transpiration and photosynthesis. This is the picture of an ordinary plant.

GROWTH FORM means nothing more than the shape or form of the plant or its parts. We find the form of plants or plant parts may be more or less modified to meet certain unusual conditions, or perform certain functions other than those mentioned above.

The first general growth forms we shall study will be those in connection with support of the leaves so that they may receive plenty of light and air. If a plant can make use of some support, it is clear that it will not have to form a large amount of wood to hold it up ; all this wood material can then be saved, and the stem is developed only for the purpose of carrying water and food. There are many plants which do just this thing.

1. TRAILING PLANTS, which grow flat on the ground and display long rows of leaves ; as *Convolvulus pluricaulis* and *Ipomaea batatas* (shakarkand).

2. SCRAMBLING PLANTS, growing over a support, and holding fast usually by means of thorns or spines, as *Rosa* spp (guláb) and *Capparis horrida.*

3. TWINING PLANTS, where the stem winds round and round some support, as *Convolvulus arvensis* and *Abrus precatorius* (gumchí).

4. CLIMBING PLANTS, holding on to a support by means of **tendrils** (special branches), as *Lagenaria vulgaris* (laukí) and *Vitis trifolia.*

5. CLIMBING PLANTS, holding fast by means of **modified leaves,** as *Gloriosa superba* and *Pisum sativum* (ḅaṛá maṭar).

6. CLIMBING PLANTS, holding fast by means of special roots along the stem **(adventitious roots)** as *Hedera helix* (ivy), *Pothos scandens,* and *Piper betel* (pán).

Epiphytes and Parasites.—**Epiphytes** are plants which grow on others for the sake of favourable position, without having to produce a long stem, and without taking anything from the supporting plants, as *Vanda roxburghii* (orchid). There are no conspicuous epiphytic plants to be found about Allahabad.

Parasites (read pp. 123-127) are plants which take either water, or both food and water from other plants (**host plant**) on which they grow. There are four kinds common about Allahabad.

1. *Loranthus longiflora* (bándá), a **water parasite** on *Mangifera indica* (ám) and *Albizzia lebbek* (sirsá).

2. *Cuscuta reflexa* (amarbel) a **total parasite** on *Zizyphus jujuba* (ber) and *Acacia arabica* (babúl).

3. *Orobanche aegyptica*, a **total parasite** attached to to the roots of *Brassica juncea* (rái) and *B. campestris* (sarson), and other crucifers.

4. *Striga lutea* ; a **total parasite** attached to the roots of many kinds of grasses.

Study examples of the above growth forms, and clearly understand the advantage of each. **Sketch** one example of each to show the most important features. **Sketch** bándá and amarbel, and describe the way they live.

9. Growth forms—Modifications for Vegetative Propagation.

Read Chapters 5 and 6.

In addition to the method of sexual reproduction, a large number of plants are able to produce new plants by separation of a portion of the parent. This is not so much " re-production " (the making of something new) as it is a propagation of something that is already made. So we shall speak of the process as **vegetative propagation.** Although roots and leaves sometimes take part in the process, the stem is the most important organ for vegetative propagation.

Advantages of Vegetative Propagation—A process that is of such frequent occurrence must be of distinct advantage to plants. Sexual reproduction combines the characters of two parents, and this is believed to be of greatest importance in the life of plants in general ; of course vegetative propagation cannot do this. The plants produced by vegetative propagation are not "new" in the strict sense of the word ; but the process does show certain advantages over sexual reproduction ;

(*a*) New plants can be produced before the parent plant becomes mature, as in *Agave* spp.

(*b*) It is a much more certain process, as the young plant remains attached to the parent until it is well started, as in *Musa sapientum* (kelá).

(c) New plants may be produced under very severe conditions, as in *Cynodon dactylon* (dúb).

(d) New plants can be produced when most of the parent plant is dead, as in *Solanum tuberosum* (álú) and *Colocasia antiquorum* (ghúyáṉ).

Think over these facts, and understand that they are *real* advantages.

ORGANS THAT TAKE PART IN VEGETATIVE PROPAGATION.—Almost any part of some plants can give rise to new plants, but in general the stem is the most important organ. The parts may or may not be modified in form. The important thing is that they must come into contact with the soil to complete the process.

METHODS VEGETATIVE PROPAGATION :

1. By stems arising from roots, as in *Dalbergia sisso* (shísham).

2. By ordinary trailing stems rooting at the nodes ; the lateral bud at each node then grows out into the stem of a new plant, as *Cynodon dactylon* (dúb) and *Ipomaea batatas* (shakarkand).

3. By specialised thick stems filled with food material ;

(a) Rhizome (merely an underground stem), as in *Canna indica* and *Andropogon intermedius.*

(b) Tuber, a short thick portion of a rhizome, as in *Solanum tuberosum* (álú).

(c) Corm, a short thick upright underground stem, as in *Musa sapientum* (kelá).

4. By leaves, as in *Bryophyllum calycinum* where new plants may arise in each of the notches of a leaf.

SKETCH an example of each of the methods of vegetative propagation, showing clearly exactly how the now plant is produced. Hang up a leaf of *Bryophyllum* in the laboratory, and observe the formation of new plants ; **sketch.**

USE MAN MAKES OF VEGETATIVE PROPAGATION.—The fact that plants can propagate vegetatively makes it possible for man to use the process for securing large numbers of new plants easily and certainly and in a short time. He does this in the following ways.

1. By **cuttings**, where a stem is cut off and put into the ground to make a new plant (kalam lagáná).

2. By **grafting**, where a stem is cut off and inserted in the cut end of another stem (paiwand) ; used with ám.

3. By separating parts of rhizomes, as in *Canna ;* or tubers, as in *Solanum tuberosum* (álú).

Try some of these methods in the garden, and WRITE COMPLETE NOTES on the results.

10. Growth forms—Modifications for Perennation.

READ Chapters 5 and 6.

PERENNATION means the remaining alive of part of a plant through conditions so severe that the rest of the plant dies. Large woody plants live through the hot season without much change. Smaller plants have to save alive certain more or less modified parts, while the rest of the plant dies. This is particularly true of herbs. The parts that remain alive are called **perennating organs.** Both stems and roots serve as perennating organs, sometimes together, sometimes separately. In every case there must be a supply of food stored up to permit vigorous growth of the plant the following season. Another fact to remember is that very often modifications for vegetative propagation also serve as perennating organs, so we may repeat some of the examples used in the preceding exercise.

KINDS OF PERENNATING ORGANS :

1. Stems alone :
   (*a*) RHIZOMES, as in *Canna indica.*
   (*b*) TUBERS, as in *Solanum tuberosum* (álú).
   (*c*) CORMS, as in *Musa sapientum* (kelá).
2. Stem together with leaves (**bulbs**), as in *Allium cepa* (piyáz).
3. Stem together with root, as in *Brassisa napa* (shalgam) and *Daucus carota* (gájar).
4. Stem, together with leaves and root, as in *Brassica oleracea* (gobhí).
5. Roots alone, as in *Ipomaea batatas* (shakarkand).

SKETCH examples of each of these kinds of perennating organs, and explain clearly how they perform their work.

Put out perennating organs of various kinds in the garden and observe the way they give rise to complete plants.—WRITE NOTES.

USE OF PERENNATING ORGANS BY MAN.—Because these organs store large quantities of food material, they are valuable as food for man and animals. **Make a list** of perennating organs used as food by man. **Write** a paragraph on the topic "The use of perennating organs of plants by man."

11. Elementary Ecology.

ECOLOGY is the study of plants in relation to the conditions under which they grow. Usually it refers to plants as they are growing wild. Plants growing naturally may be considered from two quite distinct points of view:

1. In relation to the supply of water.
2. In their society relations. We shall study this next year.

PLANTS IN RELATION TO WATER SUPPLY. Plants are constantly losing water through their leaves. When the supply of water about the roots is plentiful, the loss of water is of little importance. But when the supply of water is small, and when transpiration is excessive, as it is during April and May, the plant has great difficulty in collecting water as fast as it is lost through the leaves. Indeed, many small plants find it quite impossible, and die. Water supply profoundly affects the character of plants, and on the basis of water relations, plants are divided into three great classes: hygrophytes, mesophytes, and xerophytes. **Hygrophytes** are plants growing where there is always a plentiful supply of water, as in water and on wet soil; or where the water loss is small, as in humid climates and during the monsoon. **Xerophytes** are plants gowing where the water supply is scanty, or where the water loss is very great, as in deserts, and during the hot season. **Mesophytes**, as the name indicates, are plants midway between hygrophytes and xerophytes.

Practically all of the hygrophytes of the Plains grow either in water, or in damp places during the monsoon and early cold season. True hygrophytes on land simply disappear during the dry season; they appear again the following season either from perennating organs or seeds. We have many plants that might be classed as xerophytes, especially those herbaceous forms that flourish during the hot season. The bulk of the vegetation probably should be classed as mesophytes. As dry weather comes on herbaceous mesophytes adapt themselves to decreasing water in the soil and increasing loss of water through the leaves, by the simple process of dropping as many leaves as is necessary. Large plants, like trees, have deep root systems and can always find sufficient water.

For this study we shall take a field trip, to observe plants of the above three classes. **Write** an account of your observations, using the following outline:

(*a*) Conditions under which hygrophytes, mesophytes, and xerophytes grow.—

(1) Amount of water in the soil.

(2) The evaporating power of the air—humidity and wind.

(*b*) General characters of hygrophytes, mesophytes, and xerophytes.

(1) Size and thickness of leaves.

(2) Texture of the leaves.

(3) Hairiness of the plant.

(4) Size and texture of the stem.

(5) Size of the root system.

(6) Methods of decreasing water loss.

(7) Modifications for storing water.

(*c*) The way they adapt themselves to change of season. Illustrate your account fully by reference to actual plants.

12. Economic Use of Plants.

Here we are to study the uses that man makes of plants. Remember that besides supplying all animals with food either directly or indirectly, plants supply a large number of other fundamental needs of man.

WRITE AN ESSAY in your notebook on the subject "The use man makes of plants," using the following headings as a basis ;

Food

Fuel

Clothing

Medicines

Building materials

Ornamental purposes

Other purposes

For the most important plants and uses, give also :

The scientific and vernacular names.

What each is used for.

The part of the plant that is used.

How it is prepared.

The importance of this use.

A STUDY OF PLANTS ACCORDING TO THE INTERMEDIATE SYLLABUS.

We shall now begin the study of the course in Botany as it is outlined in the Intermediate syllabus. RANGACHAIRI'S **Manual of Elementary Botany for India**, 2nd Ed., (Government Press, Madras) will be the text book. Refer also to GAGER'S **Fundamentals of Botany** (Blakiston, Philadelphia).

The Compound Microscope.

Much of the work from here on will be with plants and parts of plants too small to be studied with the unaided eye. You will therefore be supplied with a compound microscope, and must learn how to use it. The word "microscope" is derived from two Greek words meaning "small" and "an instrument for viewing". It consists essentially of a strong lens in each end of a tube, with various other parts for supporting and moving them. Examine a compound microscope and find the following parts :

BASE, a heavy horseshoe resting on the table.

PILLAR, attached to the base and supporting the parts above.

STAGE, on which the object to be examined is placed.

ARM, a continuation of the pillar, above the stage, for supporting the

TUBE, at the ends of which are the lenses.

EYEPIECE, the lens at the upper end of the tube.

OBJECTIVE, the lens at the lower end of the tube.

INCLINATION JOINT, on the upper end of the pillar, by means of which the microscope may be tilted backwards.

DIAPHRAGM, an opening, adjustible in size, through the stage just beneath the objective.

MIRROR, for reflecting light through the object to be examined : one side is **concave** and the other **plane**.

COARSE ADJUSTMENT, a rack and pinion for rapidly moving the tube up and down.

FINE ADJUSTMENT, for slowly and delicately moving the tube up and down.

NOSE PIECE, a rotating piece screwed into the lower end of the tube, for carrying two or more objectives ready for instant use.

Make a **sketch** of a microscope and label all the above parts. Become familiar with the construction and use of the various parts, so far as you can observe them from the outside.

An objective is a complicated lens which makes a real image of the object that is being examined ; this image is near the upper end of the tube, and is in turn magnified by the eyepiece. The coarse adjustment is for rapidly moving the objective into the proper position above the object ; the fine adjustment is used finally to move the objectives into the exact position where the object is seen most distinctly. This process is known as **focusing**. Modern microscopes have at least two objectives screwed into the nosepiece : a shorter one, **low power** (l. p.), which magnifies about 10 diameters ; and a longer one, **high power** (h. p.), which magnifies about 45 diameters. In order that there may be enough light on the object for the eye to see the image clearly, a beam of light is reflected through it by the mirror from below.

HOW TO MAKE A MOUNT.—The object to be examined is placed on a glass **slide** in a small drop of **mounting medium**, usually water or dilute glycerine, and covered with a thin **cover glass**. Such a preparation is spoken of as a **mount**. Both slide and coverglass must be clean. Both should be handled by the edges, and not by the surfaces, so as to avoid leaving finger marks on them. Use only enough mounting medium to fill the spaces beneath the coverglass.

Avoid air bubbles in the mounting medium. The surface of the slide should be free from water, and there must be none on the side of the coverglass, or it will get on the surface of the objective, and soil it, and make a clear bright image impossible.

HOW TO USE THE MICROSCOPE—HANDLING. Some microscopes are made to be carried by the arm ; no special care need to be exercised in handling them. Old style microscopes have the fine adjustment mechanism inside the arm in such a manner that lifting the instrument by the arm throws all the weight on the delicate threads of the fine adjustment screw : these machines *should be lifted by the pillar and base*, and not by the arm. Always handle the microscope gently.

POSITION FOR USE —Place the microscope on the table directly in front of you, with the mirror side away from you. The chair you sit in should be just high enough that when you sit straight and then lean over the microscope the eye will naturally come just above the eyepiece.

LIGHT.—Adjust the mirror so that light from a window will be reflected through the diaphragm and into the tube. The mirror should always be directly beneath the stage—the mirror arm should always be straight down. Do not attempt to use direct sunlight as a source of light ; the best light is from a bright white cloud. Never leave the microscope standing in the sunlight. Use the plane mirror for l. p. and very bright light ; and the concave mirror for h. p. or dull light.

FOCUSING.—Alway see that the l. p. is in position :

1. When putting a mount on the stage.
2. When removing a mount from the stage.
3. When you are through with the microscope for the day.

Always find the object with the l. p. objective first, then if you wish to use the h. p., carefully swing the h. p. objective into position, and complete the process of focusing with the fine adjustment. In good microscopes, when an object has been brought into sharp focus under l. p., it should also be approximately in focus when the h. p. is swung into position. However this is often not true of old or cheap microscopes, so you should always be careful in turning from l. p. to h. p. to see that the objective does the strike the coverglass ; if it does strike, there is danger of breaking the coverglass, of ruining a fine mount, and of scratching the lens.

When the microscope is *properly focused* there is little or no strain on the eyes and no danger whatever of injuring the eyes.

CLEANING.—A microscope is a delicate instrument, and all parts should be kept clean. Do not attempt to take the microscope apart; do not play with it. Do not touch any of the lenses with your fingers or other objects, and *never try to clean them*. If they become soiled, call the Instructor to clean them for you. *At all times be careful.*

STUDY OF THE CELL.

SECTION CUTTING.—Many objects must be cut into thin **sections** with a **section razor** before they can be studied. Hold the object to be sectioned in the left hand ; flood the razor blade with water and hold it in the right hand with the edge toward you ; cut the sections with a sliding stroke. The Instructor will demonstrate the proper way to cut sections. With a little care and practice any student can soon learn to cut good sections.

Cork Cells.

Living substance or **protoplasm** is a viscid, granular, semi-transparent substance. The protoplasm of a plant is divided up into little units or **cells**, each surrounded by a **cell wall**. Cork is dead tissue ; the protoplasm has disappeared and only the empty cell walls remain. The first plant cells to be studied were from sections of bottle cork, so of course only the walls were seen, and "cell" originally meant the walls surrounding an empty space. We now know that it is the protoplasm, and not the lifeless cell wall, that is the important part of a cell.

Cut sections of bottle cork that has been boiled in water. Mount in water and examine. Observe the rectangular spaces bounded by cell walls.

Cut sections of a cork that has *not* been boiled; mount and observe that the cells are filled with air. Become familiar with the appearance of **air bubbles** in mounts, for they will be met with throughout the course, and often are mistaken for other objects the student is expected to see.

Treat other dry sections with alcohol; mount and examine. Alcohol will wet the dry cell walls and drive the air out of the cells, but water will not.

SKETCH a few cells enlarged.

Reagents and Their Use.

After considerable experience it is rather easy to recognize the important features of a section, without any special treatment. But the beginner will find it necessary to use reagents to make the parts distinct enough that he can recognise them. Reagents act chemically, either by colouring the various parts differently, or by colouring some parts and not others. Usually, the section should be treated with the reagent before the coverglass is put on.

The most common and valuable reagents are :

IODINE : stains lignified cell walls (especially xylem) brown; protein (protoplasm) dark brown; and starch grains blue.

CHLOR-ZINC-IODIDE: acts the same as iodine, and in addition colours cellulose cell walls blue.

PHLOROGLUCIN AND HYDROCHLORIC ACID : colours lignified cell walls red. First add a drop of phloroglucin, solution, then a drop of strong HCl.

ANILINE SULPHATE : colors lignified cell walls bright yellow.

SUDAN III : stains fats and oils yellowish-red. It acts rather slowly. Cork cell walls and cuticle also are coloured red.

MILLON'S REAGENT : gives protein a brick-red colour. The action is slow, and may be hastened by gentle heating.

FEHLING'S SOLUTION : is used to test for simple sugars (**reducing sugars**). When the reagent is boiled with reducing sugar, the copper is reduced and precipitated as brick-red copper oxide,

The above statements are intended mainly for reference purposes They will not be fully understood at first, but will become clear as you gain experience.

Structure of the Plant Cell.

A complete plant cell consists of : cell wall; protoplasm; and lifeles food and waste substances.

Protoplasm is for convenience divided into nucleus and cytoplasm, and the latter often contains chloroplasts and other specialized living structures. Often

there are spaces or vacuoles in the cytoplasm, filled with a watery fluid. It will be difficult to find a single cell that will show all of these parts clearly; therefore we shall find and study the parts in a number of different cells.

Cut a t. s. of the stem of some herbaceous plant (any species of *Amaranthus* is good), mount, and examine the large pith cells in the centre. In the living or fresh condition the cell contents are so nearly transparent that it will be necessary to stain the section to see the various parts distinctly.

Remove the coverglass, stain with iodine, and examine again. Inside the cell wall you will see a brownish granular substance, the **protoplasm**. The thin portion of the protoplasm, filling up most of the cell, is **cytoplasm**; while the dense rounded body embedded somewhere in it is the **nucleus**. **Draw** a single cell greatly enlarged (at least an inch in diameter).

CHLOROPLASTS are little dense grains of cytoplasm, containing a green substance (**chlorophyll**) by means of which the plant makes its own food. Cut a fresh section of the above stem, mount without staining, and look for cells near the margin that contain green bodies, chloroplasts. **Draw** a single cell enlarged.

Mount a living leaf of a moss plant (the leaves of this plant are only a single cell in thickness), and observe the cells packed full of chloroplasts. **Sketch** a single cell.

THE CELL IN PREPARED SECTIONS.—Examine prepared sections of the stem tip of *Hydrilla*, or of a root tip, or of any available young tissue. In the nucleus you will see a small very deeply-staining grain, **nucleolus**. The cytoplasm will be clearly stained. The colourless space is the **vacuole**. You probably will not be able to see any other parts. **Draw** a single cell greatly enlaged, to show all the details you can make out.

CELL WALL.—Cut a t.s. of a stem of some herbaceous plant, and stain with chlor-zinc-iodide. The blue colour of the walls of the pith cells indicates that they are composed of cellulose. Do you find similarly coloured walls in any other part of the section ?

Observe also that the walls of the xylem cells are stained deep brown, the same as if they were stained with iodine alone. These walls therefore are composed of **lignin**; they are said to be **lignified**.

Treat another section with phloroglucin and HCl, and note the colour of the lignified walls. This is one of the bests test for lignified tissue.

Treat another section with aniline sulphate, and observe the colour of the xylem.

Food and Waste Substances in the Cell.

PROTEIN is always present in protoplasm, but as a stored food is found almost nowhere except in seeds. Cut sections of soaked seeds of *Zea mays* (makái) or *Cicer arietinum* (chaná), cover with Millon's reagent, and gently heat. Observe the red bits of protein in some of the cells.

FATS AND OILS are stored in large amounts in some seeds and fruits, and small drops are scattered here and there in almost all parts of the plant. Cut sections of the seed of *Ricinus communis* (rendí) *Arachis hypogea* (mungphalí), or unripe fruit of *Musa sapientum* (kelá), and treat with an alcoholic solution of Sudan III for a few minutes. Prevent evaporation of the alcohol as much as possible. Then drain off the reagent, mount in glycerine, and examine. Nothing but oil will be stained.

Cut a t. s. of a year-old stem of *Artocarpus lakoocha* (barhal), stain and mount as above. A small amount of oil, in the shape of minute droplets, will be found scattered through the section. Note also that the walls of the cork cells on the outside of the section are stained red; this is because cork is made waterproof by a fat-like substance, **suberin**.

CARBOHYDRATES are the most abundant and widely distributed of all stored food substances. **Starch** is the most common form of carbohydrate, and is found in immense quantities in seeds, fruits, and perennating organs (stems and roots), and in smaller amounts in practically all other parts of the plant. **Reducing sugars**, especially **dextrose**, are widely distributed: in leaves, as the first product of photosynthesis; in other parts of the plant as the form in which carbohydrates are transported; and in fruits, to make them edible, so that animals will eat them and disseminate the seeds. **Sucrose** (chíní, cane sugar), a non-reducing sugar, is the storage form of carbohydrate in a few plants, as *Saccharum officinarum* (úkh and ganná) and *Beta vulgaris* (chukandar).

STARCH $(C_6 H_{10}O_5)_n$.—Cut sections of soaked seeds of *Triticum vulgare* (gehún), and of the tuber of *Solanum tuberosum* (álú), mount, and observe the cells filled with large nearly-transparent starch grains. Now treat the sections with dilute iodine, and study the colour reaction. Iodine is the best test for starch.

Cut a t.s. of a young stem of almost any woody plant, strain with iodine, and observe starch grains in many of the cells.

DEXTROSE $(C_6H_{12}O_6)$.—Add some Fehling's solution to a solution of gúr in a test-tube, and gently heat to boiling. What happens? The dextrose reduces the blue $Cu(OH)_2$ of the Fehling's solution to red Cu_2O, which settles out as a precipitate.

Crush a piece of ripe fruit of *Musa sapientum* (kelá), or *Anona squamosa* (sharífa) and treat with Fehling's solution. What is the result ?

SUCROSE ($C_{12}H_{22}O_{11}$)—Treat a solution of sucrose in a test-tube with Fehling's solution. What is the result ?

Boil another sample with a few drops of dilute (5°/₀) HCl for a short time, then treat with Fehling's solution. What is the result ? When boiled with dilute mineral acid the sucrose is **hydrolyzed**, *i.e.*, breaks up into simple reducing sugars, **dextrose** and **laevulose** (both $C_6H_{12}O_6$).

Repeat this experiment, using a piece of úkh or ganná instead of sucrose. What is the result ?

HYDROLYSIS OF STARCH.—Crush a piece of álú in water, and treat with Fehling's solution. What is the result ?

Hydrolyze another sample with dilute HCl , and treat with Fehling's solution. What is the result ? What does it tell us about the composition of starch ? Repeat the above experiment, using crushed gehún, chaná, or other seeds.

CALCIUM OXALATE. The waste substance CO_2 easily passes out of the plant (How ?), but solids cannot be eliminated. They are changed into substances harmless to the plant, and stored in the cells. One of the most common of these substances is **calcium oxalate**. Cut sections of the leaf of *Agave* and look for bundles of needle-shaped crystals of calcium oxalate in some of the cells. **Sketch** a single cell containing crystals.

WRITE A COMPLETE ACCOUNT of the staining reactions of the cell and its contents.

Mitotic Cell Division.

Cells increase in number by division. Cell division always is preceded by division of the nucleus. Two methods of division of the nucleus are known :

AMITOSIS (or **indirect division**), in which the nucleus does not undergo much change. This method is rare and unimportant, and will not be studied.

MITOSIS (Greek "mitos" = a thread or web) (**karyokinesis,** or **indirect division**), in which the nucleus passes through very complicated changes. Mitosis may be found and studied wherever cells are dividing in the plant. Root tips of *Allium cepa* (piyáz) or *Vicia faba* (bakalá) furnish satisfactory material. Study prepared sections. Observe that in many of the cells the nuclei are round and filled with a fine network, **reticulum**, of deeply-staining substance, **chromatin**; embedded in the chromatin reticulum are one or more round deeply-staining **nucleoli**. The nucleus is surrounded by a delicate **nuclear membrane**. Such a nucleus is said to be in resting condition, although it really is actively directing and controlling all the various activities of the cell.

When a nucleus is preparing to divide, the chromatin reticulum gradually condenses, finally taking the form of a long slender coiled thread, **spirem**. This spirem becomes shorter and thicker and finally divides into a definite number (constant for each species of plant and animal) of rod-shaped pieces, **chromosomes.** Each chromosome then divides longitudinally into two. In the meantime the nucleolus disappears ; a **spindle** of delicate fibres radiating from two opposite **poles** arises ; and finally the nuclear membrane disappears.

The chromosomes arrange themselvee about the centre of the spindle with one end attached to the spindle fibres to form an **equatorial plate.**

Then the half chromosomes, **daughter chromosomes**, begin to travel toward opposite poles of the spindle ; each group of daughter chromosomes contains the same number as the original nucleus did. As the daughter chromosomes approach the poles, the spindle becomes broader, and a row of granules forms across the centre. These granules unite to form a **cell plate,** which broadens and finally joins the old cell walls to form the new wall between the new **daughter cells**. The chromosomes of each group now organize into a news nucleus, with a new nuclear membrane, and new a nucleolus. The chromosomes spread out into a resting reticulum, and the process of mitotic cell division is completed.

DRAW in as much detail as you have time for :

1. A cell with the nucleus in resting condition.
2. A cell with the nucleus in the spirem stage.
3. A cell with the spindle complete and the chromosomes in the equatorial plate.
4. A cell with the daughter chromosomes moving toward the poles, and the cell plate forming.
5. Cell division completed.

Everyone knows that offspring resemble their parents. This is as true of daughter cells as it is of ním trees. We say that this resemblance is due to **heredity**. Hereditary qualities are carried in some way by the chromatin ; when a cell divides the chromosomes carry its hereditary qualities into the daughter cells. It is the chromosomes of the germ cells that carry the hereditary qualities of the ním tree into the new plants. Nuclear division is so complicated because of the necessity for accurate equal distribution of the hereditary qualities to the daughter cells.

Mitosis in higher plants differs from that in animals in that there are no centrosomes, and the new wall between the two daughter cells is formed by a cell plate, and not by constriction of the parent cell wall.

A STUDY OF REPRESENTATIVE PLANTS OF THE PLANT KINGDOM.

Formerly it was believed that every kind of plant and animal was made by a separate act of creation. Now the belief has become general that higher forms of life have developed from lower forms by a slow process of change, that is, by evolution. If evolution is the method of creation, then all plants must be related to each other, even though the relation may sometimes be very distant and difficult to see. We shall be able to study our representative plants, not merely as examples selected out of the plant kingdom to be memorized, but as illustrating various important stages in the evolution of the plant kingdom.

The plant kingdom may for convenience be divided into four great groups :

THALLOPHYTES (thallus plants), containing the simplest plants

BRYOPHYTES (moss plants).

PTERIDOPHYTES (fern plants), and

SPERMATOPHYTES (seed plants), containing the most advanced plants.

The characters of these great groups will become clear only by the study of examples.

THALLOPHYTES.

Thallophytes (thallus plants) are those in which the plant body is not differentiated into true root, stem, and leaves. There are two great divisions of thallophytes :

ALGAE ; those which possess chlorophyll, and sometimes other photosynthetic pigments, and are therefore capable of making their own plant food.

FUNGI ; those without any photosynthetic pigment, and which are therefore dependent on food that has been prepared by other organisms.

Algae.

Algae are divided into a number of groups, of which we shall notice only four : **Myxophyceae** (blue-green algæ) ; **Chlorophyceae** (green algæ) ; **Phaeophyceae** (brown algæ) and **Rhodophyceae** (red algæ).

Myxophyceae.

Myxophyceæ (blue-green algæ) are simple plants, sometimes existing as single cells, sometimes as irregular masses, or as chains or **filaments** of cells ; all have a very primitive cell structure ; the colour is bluish-green. They are widely distributed throughout the world, and often become abundant in quiet stagnant water. Many kinds are found about Allahabad, but no examples will be studied.

Chlorophyceae.

Chlorophyceæ (green algae) are thallus plants having chlorophyll as the photosynthetic pigment. They are very widely distributed, and are common in water everywhere throughout India. They constitute the bulk of the growths in water known as "káí". Four examples will be studied.

Chlamydomonas.

Chlamydomonas is a very minute plant, consisting of a single independent cell. It is found occasionally in great abundance in small temporary pools during sunny periods in the monsoon. Fresh material may be not be available for study.

MOUNT some of the material provided, and look for minute ovoid nearly-transparent bodies. They are very small, and require care and patience to find. When you have found a cell under l. p., study it with h. p. Observe the following parts : the addition of iodine will make them show more distinctly : (1) the **chloroplast**, a cup-shaped (U-shaped as seen from the side) body filling the large end of the cell ; (2) the **pyrenoid**, a small spherical conspicuous body embedded in the chloroplast ; (3) the **nucleus**, a small body lying between the chloroplast and the smaller end of the cell ; (4) the **cilia**, two very slender delicate threads at the smaller end of the cell ; in preserved material most of them are likely to be broken off ; (5) the **contractile vacuoles**, two in number, may perhaps be seen at the base of the cilia. In case you cannot find all these parts, look for them in the demonstration microscope. **Draw** a single cell highly magnified to show all the above parts you can find. Colour the chloroplast natural green if you wish to do so.

THE REPRODUCTIVE PROCESSES are very similar to those found in *Ulothrix*. The contents of a cell divide to form 2, 4, or 8 small cells, each of which gradually assumes the form and structure of the parent cells. These cells, **zoospores** (animal spores), escape by the breaking of the old cell wall, swim about in the water, and soon grow to full size. This is **asexual reproduction.** You may find exampes of **sexual reproduction**; it differs from asexual reproduction only in the fact that there are more divisions of the parent protoplast, the cells are consequently smaller, and they must join together in pairs, **conjugate,** before they can give rise to new plants. **Sketch** whatever stages in reproduction you can find.

UNDERSTAND :

1. That *Chlamydomonas* is very small.
2. That it consists of a single cell.
3. That this cell is capable of making its own food by means of the chloroplast, and is therefore quite independent.
4. That it swims freely in the water by means of the cilia.

Ulothrix.

Ulothrix is an alga found in fresh running water, and is common throughout the world. It is not common in the vicinity of Allahabad. It is studied because

1. It is a simple many-celled plant, and
2. It is an excellent example for the study of the beginnings of reproductive processes in plants.

Mount some of the preserved material and observe the following features; compare the preserved material with stained permanent preparations. The plant consists of a large number of cells arranged end to end so as to form a long thread or **filament**. Under h. p. examine carefully a single cell and find : (1) the **chloroplast.** Each cell has a single chloroplast, as in the case of *Chlamydomonas*, but instead of being cup-shaped, it is ring-shaped and lies in the middle of the cell just inside the cell wall ; (2) there are several **pyrenoids** embedded in the chloroplast ; (3) the **nucleus** lies between the chloroplast and the cell wall, and is flattened.

REPRODUCTION.—In places where *Ulothrix* is abundant, all stages of reproduction may be found in a single collection. The reproductive processes are very simple, and should be studied carefully. Two kinds of reproduction occur, asexual and sexual.

ASEXUAL REPRODUCTION.—The protoplast (that is, the living part) of a cell divides to form 2, 4, 8, 16, or even 32 little protoplasts, which soon assume a structure very much like that of an adult cell of *Chlamydomonas*—having a chloroplast, a pyrenoid, a nucleus, and four cilia. These little cells are called **zoospores.** They escape through a hole in the wall, swim about for a while, then settle down to the bottom and start dividing to form new filaments. Note that each zoospore is able to produce a new plant *all by itself.*

SEXUAL REPRODUCTION.—The same process of division of the protoplasts of the cells takes place, but it goes on further, so that more reproductive cells are produced, and they are smaller than zoospores. They have the same structure as zoospores, but have only two cilia instead of four. They escape from the old mother cell, swim about for a time, then join together in pairs. This joining together is known as **conjugation,** and the cells that conjugate are called **gametes.** The single cell resulting from conjugation is a **zygospore.** The zygospore becomes thick-walled, and rests for a time. Then the protoplast divides to form four zoospores, which escape and form new filaments.

SKETCH a filament to show the relation of the cells. DRAW a single cell

greatly magnified to show the structure; colour the chloroplast green, if you wish. DRAW a cell containing zoospores. DRAW a cell containing gametes.

UNDERSTAND :

1. How ordinary cell division in a single-celled plant like *Chlamydomonas* results in the production of new plants ——is a kind of asexual reproduction.

2. That ordinary cell division in *Ulothrix* results in growth of the filament, and not in reproduction.

3. That reproduction is by special small cells, derived from repeated divisions of vegetative cells.

4. That two kinds of reproductive cells are formed, which are alike in appearance, but which behave differently.

5. That the larger of these cells can produce new plants by themselves, hence are zoospores.

6. That the smaller cells must join together in pairs to produce new plants, hence are gametes.

7. That the *reproductive cells* of *Ulothrix,* both zoospores and gametes are like the *ordinary vegetative cells of Chlamydomonas.*

8. That the gametes of *Ulothrix* are all alike, hence are called **isogametes**.

THINK about these relations till they becomes clear to you. It is important to understand them, for we are here studying the very beginnings of sexuality in plants. There still is no suggestion of sex—of male and female plants, or male and female gametes. As you think over these problems, you will begin to see the importance of understanding a plant like *Ulothrix*; it is a starting point for understanding the more complicated structures and processes found in higher plants.

Oedogonium.

Oedogonium is not in the syllabus, but it will be studied briefly to illustrate certain very important facts. It is a common alga throughout the world, and is often abundant in fresh clean water about Allahabad.

MOUNT some of the material provided and observe that the plant consists of a filament of cells, like *Ulothrix*. Ordinary cell division results merely in growth of the filament. It is on account of its sexual reproduction that *Oedogonium* is so important

ASEXUAL REPRODUCTION is by zoospores; the process differs somewhat from that found in *Ulothrix*, in that each protoplast gives rise to a single large zoospore.

SEXUAL REPRODUCTION shows a great advance over *Ulothrix*. Certain cells of the filament become very large and the protoplast of each becomes a single large gamete, without cilia, and containing an enormous amount of food material in the form of starch grains. Other vegetative cells divide several times and the small resulting cells produce small gametes, each having a single chloroplast, a nucleus, and cilia, like the isogametes of *Ulothrix*. Where there is such a difference as this in the size of the gametes, the large cells are called **eggs** and the small ones **sperms**. The more or less specialized cells in which the eggs are produced are known as **oogonia**; those in which the sperms are produced are **antheridia**. The sperms are liberated, swim to the oogonia, enter through pores, and fuse with the eggs.

OTHER NEW TERMS must be used in connection with these processes. When the gametes are unequal, they are said to be **heterogametes**; when they fuse the fusion is not called conjugation; but just plain **fertilization**. The term conjugation is restricted to fertilization by isogametes. The product of *any* fertilization may be spoken of as a **zygote**; when the zygote is produced by the fertilization of heterogametes, it is an **oospore**. The oospore of *Oedogonium* rests for a while, then gives rise to new filaments. We are now in a position to understand more easily *spirogyra* and its peculiar reproductive processes.

Spirogyra.

Spirogyra is everywhere one of the most abundant algae. It is very common about Allahabad, in rivers, lakes, and stagnant pools.

MOUNT some of the material provided and observe that the plant is a filament of cells. Under h. p. examine a single cell and find the following parts; **chloroplasts**, the green bands, one or more in number (depending on the species) wound spirally just beneath the cell wall; **pyrenoids** scattered throughout the length of the chloroplasts; the **nucleus** in the centre of the cell, surrounded by cytoplasm, and held in position by strands of cytoplasm that radiate outward and connect with the thin layer of cytoplasm (called "primordial utricle" in old text books) lining the cell wall, and in which the chloroplasts are embedded; the **vacuole**, all the space in the cell that is not occupied by cytoplasm; it is a space filed with watery fluid, the **cell sap**.

If these parts are seen with difficulty, staining with iodine will render them more distinct. Observe that the pyrenoids turn blue, indicating the presence of starch. Compare the preserved material with permanent slides.

SEXUAL REPRODUCTION—There is no regular method of asexual reproduction; sometimes the cells composing the filaments separate, and each may continue dividing to form a new filament, but the process is not very common. In sexual reproduction, two filaments lying side by side put out tiny tubes from

adjacent cells; these tubes meet and fuse, forming what is known as **conjugation tubes.** The entire protoplast of one of a pair of cells passes through the conjugation tube and fuses with the protoplast of the other cell. Two filaments in conjugation present a ladder-like appearance. Since the conjugating protoplasts or gametes are alike, they are **isogametes**; their fusion is a **conjugation**; and the resulting zygote is a **zygospore.** The zygospore forms a thick wall about itself and rests for a while; then the protoplast bursts the thick wall and begins to divide to form a new filament.

SKETCH a filament. **Draw** a single cell, and colour the chloroplasts natural green if you wish. **Draw** about 3 stages in conjugation: (1) conjugation tubes forming; (2) one protoplast passing through the tube charge to; and (3) the zygospore completed.

UNDERSTAND—That *Spirogyra* (and its relatives) is peculiar in not forming any kind of zoospores; that the gametes do not develop the structures usually found in gametes, but are *peculiar* in that they are *ordinary vegetative protoplasts* that have undergone just enough change to enable them to pass through the conjugation tubes. Compare this with the gametes previously studied. There is no difference in appearance between the two conjugating gametes, and they behave alike, except one shows a slight power of movement—they are **isogametes.** It is for these reasons that *Spirogyra* is not a good form with which to begin the study of algae; it is used so much because it is found everywhere, and all stages are easily collected.

Review of Green Algae.

1. What is the simplest form of plant body? How are more complex forms derived from the simple?
2. What is the structure of an alga cell? What parts are always present?
3. What is sexual reproduction? What is its purpose? How does it take place?
4. What is the origin of sex? What is the evolution of sex?
5. Give the complete life history of each of the algae studied.
6. What are the characters of green algæ?

Phaeophyceae.

PHAEOPHYCEAE (brown algae) are nearly all found in the ocean; only a few occur in fresh water. Along the coasts in temperate waters they become very abundant and some attain a great size.

Fucus is very abundent attached to rocks that are covered by water at high tide and exposed at low tide. It is studied to give some idea of the appearance and especially the characteristic colour of brown algae. Observe that the plant is attached by a **hold-fast** and branches repeatedly. Here and

there are inflated cavities, **bladders**, filled with air, to give buoyancy to the plant. The ends of the branches are enlarged and contain minute cavities in which the gametes are produced. SKETCH a plant to show the above features; colour the sketch as nearly natural colour as possible.

Rhodophyceae.

RHODOPHYCEAE (red alagae) are also marine, reaching their greatest abundance in tropical waters. Usually they are attached in water deep enough that they are never exposed even at low tide. Only a few species are found in fresh water.

Nemalion consists of branching filaments so closely packed together as to resemble a soft fluffy string. SKETCH a thread and colour it as nearly natural as possible.

Fungi.

FUNGI are found all over the earth, and are often very abundant. They are found growing on and in the soil, on decaying wood, and many kinds cause disease in living plants and animals : in fact they are found almost anywhere where there is organic material. Since they possess no chlorophyll, they must live on food that is already prepared. The bulk of the fungi use lifeless organic matter for their food, and are called **saprophytes**; for example, *Rhizopus nigricans* (phaphúnda). A very large number take their food from other *living* organisms, and are called **parasites**; for example, *Puccinia triticina* (gerúi). Because of their great economic importance as disease producers in other plants and in animals, fungi deserve more study than we shall have time to give them them. Fungi divide naturally into three groups : (1) **Phycomycetes** (alga fungi) ; (2) **Ascomycetes** (sac fungi); and (3) **Basidiomycetes** (basidium fungi). These names refer to the most conspicuous character of the groups.

Phycomycetes.

PHYCOMYCETES (alga fungi) resemble filamentous green algae in many ways, except they do not have chlorophyll. Only two forms will be studied.

Bacteria.

BACTERIA are very minute one-celled plants present everywhere, in the soil, in air, in water, and in and on the bodies of other organisms. They are of greatest importance, because of their work in causing decay of dead organisms, because of their relation to soil fertility, and because they are the cause of so many serious diseases in both plants and animals.

Bacillus subtilis (" hay bacillus ") is to be found everywhere. Almost pure cultures are easily prepared by boiling dry grass in water and allowing

the infusion to stand for some time. One stage of the organism is very hard to kill, and is uninjured by the boiling, so when the solution cools the bacillus begins to develop with great rapidity.

MOUNT some of the scum of a "hay bacillus" culture, and after locating it under h. p., focus with extreme care. Look for very slender rod-shaped nearly-transparent cells joined end to end to form long filaments. In spite of the fact that the cells are held together in filaments, each cell is quite independent. With the most careful staining and painstaking study a few details of structure have been made out in the cells, but we shall not attempt to see these details. Do you observe any movement of the cells? Some of them that are separate have cilia and are able to swim freely in the water. In this and other bacteria, staining with iodine will make the cells more distinct.

REPRODUCTION—Only **asexual reproduction** is known certainly to occur. The usual method is for a cell to divide transversely; each daughter cell grows to full size and repeats the performance. This process is known as **fission**, and may occur as frequently as once every 30 minutes. When conditions become unfavourable for continued vegetative development the contents of each vegetative cell condense into a dense body, **arthrospore** (or merely **spore**) inside the old cell wall. Study a stained slide and observe the arthrospores in many of the cells. Strictly speaking, the spores are not reproductive cells, but are developed for the purpose of maintaining life during very unfavourable conditions, when ordinary vegetative cells would be killed. It is the spores that survive the boiling when a culture of *Bacillus subtilis* is made.

SKETCH a filament greatly enlarged. DRAW a single cell greatly enlarged, and indicate the magnification. DRAW a cell containing a spore.

DIFFERENT FORMS OF BACTERIA. Bacteria are roughly classified on the basis of shape into three classes: (1) **Bacilli** rod-shaped; (2) **Cocci**, spherical; and (3) **Spirilli**, spiral-shaped. By far the largest number of bacteria are bacilli.

BACTERIA IN MATERIAL FROM BETWEEN THE TEETH. Mount some of the material from between your teeth and search for the three forms of bacteria. Such material contains a great variety of objects—fragments of food leucocytes, epithelial cells, bacteria of many kinds, and often animal organisms. Note whether any of the bacteria are moving. SKETCH as many forms as you can find.

BACTERIA IN DIRTY WATER. Mount and examine some water from a drainage ditch, and observe the various kinds of bacteria present. Filament-forming bacilli are abundant, and spirilli may be very conspicuous in such water. SKETCH several forms.

BACTERIA IN THE AIR. A common method of studying bacteria is to

separate them by diluting the solution in which they are growing, and then permitting the separated cells to divide to form colonies in a nutrient substance The colonies soon become large enough to be seen with the unaided eye. Observe culture plates that have been exposed to the air of the laboratory for a few minutes, then set away for the bactoria that have fallen in to incubate. The individual cells begin to divide rapidly, and in a day or two form masses large enough to be seen easily. In such a culture, therefore, each colony stands for a single cell that fell on the original plate from the air. Are the colonies all alike, or can you observe differences that indicate that there are different kinds of bacteria floating in the air ? WRITE FULL NOTES on this experiment. What do you conclude as to the presence of bacteria in the air ?

BACTERIA IN WELL WATER. Examine cultures that have been made from a well that is in constant use. Remember that each colony is the progeny of a single bacterium in the original water. Usually water that is suitable for drinking contains so many bacteria that it must be diluted (a definite known amount) before cultures can be made from it. WRITE FULL NOTES on this experiment. What do you conclude from this experiment ?

BACTERIA CARRIED ON THE FEET OF A FLY. Examine an incubated plate over which a house fly has been allowed to walk. The track of the fly is outlined by the colonies of bacteria. WRITE FULL NOTES on this experiment. What does this teach concerning the ability of a fly to carry bacteria ? Remember where flies live, what kinds of food they eat, and their relation to man. Because it can and does carry so many kinds of bacteria and other organisms, the house fly is rightly considered to be one of the most dangerous animals.

BACTERIA AS THE CAUSE OF DECAY. Examine a test tube of food (any kind) that has been stoppered and set away for a few days at a temperature favourable for the development of bacteria. What is the result ? How is this result brought about ? Understand the relation of bacteria to decay, and consider the value of decay in the world. WRITE FULL NOTES on this experiment.

PRESERVATION OF FOODS. Prepare three test tubes of any kind of food. Boil one tube for 20 minutes in a water bath, then stopper with a wad of cotton that has been scorched in a flame. Mix sodium benzoate to a strength of 0.5 per cent with the contents of another tube, and stopper as above. Stopper the third tube without any kind of treatment. Set all the tubes away for a few days. What is the result ? Consider the value of the different ways of preserving food by preventing the growth of bacteria ; understand what happens to the bacteria in each case. WRITE FULL NOTES on this experiment.

Rhizopus nigricans.

Rhizopus nigricans (Mucor stolonifer) (phaphúnda, bread mould) is a very common fungus on various kind of foods and other organic materials. It is specially abundant during damp weather.

EXAMINE a culture growing on a piece of bread. Such a culture may be started at any time by touching a piece of bread (dampened) to the dust of the floor, then keeping it under a bell jar to prevent drying out. The dust contains a large number of spores, which soon germinate and give rise to a mass of delicate white threads, resembling cotton wool, over the surface of the bread. Later their will appear minute white balls at the ends of some of the threads, and these balls will gradually become large and turn black—these are the reprodutive organs. The entire mass of threads is spoken of as a **mycelium**, while a single filament is a **hypha**.

Now examine the culture under the binocular microsope and observe that there are three different kinds of hyphæ : (1) long straight threads that run across the surface of the bread and serve to spread the mould; (2) shorter crooked branching threads that enter the substance of the bread and perform the double function of holding the surface mycelium in position, and of taking up food from the bread; and (3) short straight threads, **gonidangiophores**, that grow erect in bunches and bear the reproductive bodies, **gonidangia**, in which are produced great numbers of minute black non-motile spores, **gonidiospores**

MOUNT some of the material in 50 per cent alcohol and study the various kinds of hyphæ. Observe that there are are no cross walls in the hyphæ ; in other words, the entira mycelium is a single cell, though it contains a multitude of minute nuclei. Such a multinucleate cell is called a **coenocyte**. Add iodine and make out what you can of the structure of the hyphæ. Note that the cytoplasm is granular, with here and there larger grains of **food material**. You will not be able to see the nuclei, owing to their small size. Is chlorophyll or other photosynthetic pigment present ? What changes take place in the bread when *Rhizopus* is growing on it ?

ASEXUL REPRODUCTION is by means of the **gonidiospores**. Look for stages in the development of the gonidangium; the first step is the swelling of the free end of an upright hypha ; when the swelling has become large, a layer of the surface is cut off from the rest of the hypha by a wall, and the protoplasm of this layer divides into minute protoplasts, each of which becomes a thick-walled uninucleate black spore, **gonidiospore**. The part of the gonidiospore that remains projecting into the gonidangium is called **columella**. The spores become dry, blow about in the air, and when they fall on suitable food material produce new hyphæ and start a new mycelium. How many spores are produced by a single

gonidangium ? How many gonidangia by a single mycelium ? Try to estimate the total spore output of a single culture of *Rhizopus*.

SEXUAL REPRODUCTION is of frequent occurrence in many related moulds, but is rarely met with in *Rhizopus nigricans*. This is because sexual reproduction can occur only between what may for convenience be called male and female mycelia. Study the process from prepared slides. When these two kinds of mycelia come together, adjacent hyphæ put out short branches ; these branches meet and from the end of each a cell, **gamete**, is cut off. The gametes now fuse, and the zygote becomes a thick-walled black warty zygospore. The gamete-bearing branch is called **gametophore**. After a period of rest the zygospore germinates into a new hypha, and the life history is repeated.

SKETCH a mycelium growing on a piece of bread. **Sketch** a portion of a mycelium to show the relation of the three kinds of hyphæ. **Draw** a portion of a hypha highly magnified to show the structure. **Draw** stages in the development of the gonidangium—a gonidangiophore beginning to swell at the tip; a large swelling ; a gonidangium with spores formed, and showing the columella ; and a mature spore greatly enlarged. **Draw** stages in sexual reproduction—reproductive branches forming ; the gametes cut off ; the gametes fusing ; and the zygospores fully formed.

UNDERSTAND :

1. That the entire vegetative growth of a mould or fungus is called **mycelium**, while the separate threads are **hyphae**.
2. That the hyphæ of *Rhizopus* are **coenocytes**, as is the case also with many green algæ.
3. That *Rhizopus* obtains all of its food by digesting the substance of the bread and absorbing the digested substances.
4. That asexual reproduction is by means of non-motile spores, **gonidiospores**.
5. That the function of these spores, like that of zoospores, is to spread the mould rapidly.
6. That sexual reproduction is by means of **isogametes**, cut off from the ends of special short branches of the mycelium. The zygote is therefore a **zygospore**.

Ascomycetes

ASCOMYCETES (ascus or sac fungi) comprise a great group of fungi, many of which are destructive **parasites** on other plants. Like all fungi they have no chlorophyll. The hyphæ are divided up by cross walls into cells, as in the filamentous green algæ we have studied. The most characteristic feature of the

group is that the spores, here called **ascospores**, are developed in club-shaped cells called **asci** :

Peziza, a little fungus found in damp shady places dûring the rains, very well illustrates the structure of the Ascomycetes. A whitish mycelium grows as a saprophyte in the soil or on dead twigs and leaves. Later, a little cup-shaped reproductive body, **apothecium**, is formed. The inside of the cup is covered with a layer of long slender asci, each containing eight ascospores. **Sketch** an apothecium. **Draw** an ascus from the demonstration microscope.

Saccharomyces

SACCHAROMYCES (ḳhamír, yeast) are minute unicellular plants found throughout the world. They cause fermentation in plant juices and other solutions that contain sugar. A culture is easily prepared by adding a little commercial yeast (ḳhamír) to a solution of glucose sugar ; cane sugar will not do.

MOUNT some material from an active culture of yeast, and look for very small almost colourless ellipsoidal cells. How abundant are these cells in the culture ? Stain your preparation by placing a small drop of iodine at one side of the cover glass, and study the structure. Look for : (1) the **vacuole** which may be very large in old cells, and absent from young ones ; (2) a few scattered **granules of nuclear material** ; (3) and large **oil drops**. You will not be able to make out any more structure than this.

REPRODUCTION ordinarily takes place by **budding**. A little projection is put out from one end of a cell ; it grows larger, the nucleus divides, and one of the daughter nucle enters the **bud** which is then cut off as a new cell. If the plants are growing vigorously, new cells may be budded off faster than they can separate, and a short filament or **sprout chain** results. Each cell is entirely independent, however. Be sure you understand the difference between budding and fission.

ASCOSPORE FORMATION. Mount and examine some yeast that has been growing for a few days on the cut surface of a potato. The culture remains moist, but there is no sugar for growth. Under such conditions of food scarcity the contents of the cells divide into four (sometimes fewer) spores, which are believed to represent **ascospores**. These spores germinate into new yeast cells.

DRAW a yeast cell greatly magnified to show all the structure you can make out. **Sketch** stages in budding. **Sketch** a sprout chain. **Draw** a cell containing ascospores.

PHYSIOLOGY OF THE YEAST PLANT. Yeast is included in the syllabus not because of the botanical importance of the plant, but because of its industrial importance. The products formed by yeast during its growth are of great value.

Examine a vigorous culture of yeast and observe the formation of a gas; smell the culture and note the odour of alcohol in addition to the characteristic yeast smell. The process which results in the formation of CO_2 and alcohol is called **alcoholic fermentation**. WRITE NOTES on the appearance and odour of the culture.

TO DEMONSTRATE THE PRESENCE OF CO_2, prepare an apparatus so that the gas that is formed will pass through lime water. The formation of a white precipitate which is insoluble in HCl demonstrates the presence of CO_2. WRITE FULL NOTES on this experiment. **Write** the chemical reactions involved in the test, and show clearly how the test is proof that CO_2 is formed by the yeast. How would you show that the CO_2 does not come from the supply always present in ordinary air?

TO PROVE THE PRESENCE OF ALCOHOL, prepare the culture flask for distilling, and distill over a waterbath at 80°C. Note the odour of the distillate; see whether it will burn. Yeast is incapable of forming alcohol to a greater concentration than about 14 per cent, while alcohol much below 80 per cent will not burn; this is why it is necessary to distill the culture before applying the burning test. There are specific tests for alcohol, but it will scarcely be necessary to apply them; the odour and burning will be sufficient test. WRITE COMPLETE NOTES on this experiment.

UNDERSTAND:

1. That yeast is a minute unicellular plant.
2. That it is scattered by blowing in the air, and is very widely distributed.
3. That it reproduces asexually (vegetatively) by budding.
4. That under conditions of food scarcity ascospores are formed.
5. That ascospore formation is the most important feature that connects the yeast we have studied with Ascomycetes.
6. That there are some yeast-like plants that form real mycelia, like ordinary Ascomycetes.
7. That the importance of yeast lies in its power to produce fermentation, with the production of CO_2 and alcohol.

CONSIDER the industrial uses of the products of fermentation.

Disease-producing Ascomycetes. Many Ascomycetes are parasites and produce destructive diseases on other plants. One kind appears as a whitish powder on cucurbits (kaddú), causing death of the leaves. Another kind appears as white patches on the leaves of shísham. Ascomycetes are not as destructive in the Upper Gangetic Plain as in many other parts of the world, probably because much of the year is so very dry.

Basidiomycetes.

Basidiomycetes (basidium fungi) are so called, because at one stage in the life history there is either a short mycelium or a single cell, **basidium**, which gives rise to 4 spores, **basidiospores**. Basidiomycetes are important because they include some of the most destructive plant diseases known. It is estimated that the various kinds of gerúí (wheat rust) alone reduce the wheat crop by one-fourth. Most of the Basidiomycetes grow inside their hosts, so are very hard to combat. Fortunately the climate about Allahabad is so dry for most of the year that Basidiomycetes do not become as numerous or destructive as they do in many other parts of the world.

The life history of many forms is very complicated, and may include 3 distinct forms of mycelia, producing 5 distinct kinds of spores, and growing in the tissues of 2 widely different host plants.

Puccinia triticina.

Puccinia trit—(wheat rust) may be selected as an example, because it is avery common and destructive parasite on *Triticum vulgare* (gehúṉ). It differs only in minute details from *Puccinia graminis*, the form usually described in text books. We shall not have time to study the complete life history; in fact, it is not known with certainty. Wheat plants that remain green to the end of February usually show a great number of little spots of bright red powder on the stems and leaves. This powder is composed of **uredospores**, produced from the **uredial mycelium** that extends everywhere throughout the tissues of the wheat plant The spores blow to other wheat plants and infect them, and are a rapid method of scattering the disease.

Later in the season the same mycelium gives rise to another type of spores, large two-celled **teliospores**, each cell of which germinates into a basidium. It is not necessary to proceed further, as the complete theoretical life cycle of *Puccinia triticina* is not known to occur in the Upper Gangetic Plain.

SKETCH a wheat plant infected with the uredial stage of *Puccinia triticina*. SKETCH a t. s. of a leaf or stem showing a group of uredospores. DRAW a single uredospose. DRAW a teliospore.

No method is known of destroying this fungus, but there are ways of preventing or at least of lessening its ravages.

Agaricales.

Agaricales (dhartí ká phúl, mushrooms, toadstools) are very common objects during the monsoon. It is not worth while to attempt to name and study any particular species. There are very many kinds found growing in the soil, or on decaying wood, always in damp places.

Examine a specimen as it is growing in the soil. Note that there is a mycelium of white branching hyphæ ramifying through the soil. Here and there the mycelium gathers into a knot, which rapidly develops into the well-known dhartí ká phúl, on which the spores are produced. This **fructification** consists of a cap or **pileus,** borne on a stalk, **stipe** ; the whole structure is composed of a dense mass of hyphæ. On the under side of the pileus there are radiating **gills,** on each side of which there is a layer of larger cells, **basidia,** each producing four **basidiospores.** On germination the basidiospores give rise to new mycelia.

SKETCH a dhartí ká phúl, showing mycelium, stipe, and pileus. SKETCH the under side of the pileus to show the gills, and indicate the position of the basidiospores.

SUMMARY OF FUNGI. Understand clearly, and write notes.

1. What is the colour of fungi ? Method of nutrition ?
2. Give a summary of the structure of fungi.
3. How do fungi reproduce ? Can you pick out any features from the various reproductive processes which we have studied that seem to show similarity ?
4. Be able to give the life history of any of the fungi studied.
5. What is the importance of fungi ?

BRYOPHYTES

Many of the Bryophytes (moss plants) are differented into true stems and leaves, but none ever have true roots. Instead, they are attached to the earth by filamentous structures, rhizoids. The simplest Bryophytes are really thallus plants (though of course *not* Thallophytes). Bryophytes show certain features that place them far in advance of the Thallophytes :

1. They show very clearly **alternation of generations,** that is two distinct kinds of plants, a sexless (**sporophyte**) and a sexual (**gametophyte**) alternating with each other in the complete life cycle. Alternation of generations has its beginnings in the green algae ; in *Spirogyra* for example, the filament is gametophyte, while the zygospore is for a short time sporophyte. In the green algae the gametophyte is the conspicuous generation, while the sporophyte is very inconspicuous. In Bryophytes we meet for the first time an easily distinguished alternation. We shall find that there is a tendency running clear through the plant kingdom from the gametophyte to decrease and the sporophyte to increase in relative size and complexity.

2. They have **jacketed sex organs**. The most highly developed sex organs in Thallophytes are all unicelleluar. In Bryophytes the gametes are produced in special multicellular sex organs, the sperms in **antheridia,** and the eggs in **archegonia**. These organs have essentially the same structure, and consist of a single layer of sterile cells, the jacket, surrounding and protecting the gametes *All Plants above Thallophytes are Heterogamous.*

Bryophytes are divided into two groups, **Hepaticae** (liverworts), and **Musci** (mosses). No Bryophytes are included in the syllabus, but it will save time and make the higher plants more easily understood if we briefly study a few examples.

Hepaticae.

Hepaticæ (liverworts) are common plants in damp temperate and tropical regions, or during damp seasons. Four species are found locally, and the one we shall study is common.

Riccia sanguinea occurs on damp mud banks throughout the year. It is important because it combines in the life history a very simple sporophyte and a relatively simple gametophyte. We find here a starting point for the large complex sporophytes of higher plants.

The gametophyte is the conspicuous generation. It consists of a flattened thallus that branches dichotomously to form a rosette. It is attached to the mud by means of rhizoids. Along the mid-line of the dorsal side of the branches are the sex organs, sunk in tiny pits.

When the sperms mature, and there is sufficient water, they swim to the eggs and fertilize them, and the zygotes develop into porophytes.

THE SPOROPHYTE is a small spherical mass of cells that is contained throughout its life in the old archegonium. It consists of nothing more than a single outer layer surrounding a central mass of cells, each of which finally divides to form four spores. The spores germinate into new gametophytes, and the life cycle is completed. The spores are liberated by decay of the old thallus.

SKETCH a gametophyte thallus to show the general appearance, and the location of the sex organs. SKETCH a portion of a female gametophyte that has been made transparent, to show the sporophytes inside.

Musci.

Musci (mosses) are all differentiated into true stem and leaves, but they have rhizoids instead of true roots. We study moss because it is a very fine illustration of alternation of generations, and because the sex organs are very easy to find and study.

Mosses are small plants very common throughout the world. We have a

few species about Allahabad abundant during the rains and in winter, forming a soft green covering over damp earth and walls, but the rest of the year is too dry for them. All the local species are very small.

Examine the moss plants provided, and note that they consist of a **stem,** bearing **leaves,** and are attached to the earth by branching **rhizoids.** This is the gametophyte. The sex organs are borne on the upper end of the stem, usually on separate plants. The gametophyte bearing antheridia is the **male gametophyte,** and that bearing archegonia is the **female gametophyte,**

SEX ORGANS. Carefully tease apart on a slide the tip of a male gametophyte, and then mount and look for **antheridia.** They are dense elliptical bodies. You should be able to see that on the outside there is a single layer of cells, **sterile jacket,** enclosing the central mass of **sperm-producing cells.**

Similarly tease out the **archegonia** from the tip of a female gametophyte ; they are flask-shaped bodies. They too have a sterile jacket of a single layer of cells. The enlarged basal portion of the archegonium is the **venter,** which contains a single **egg** ; the slender portion is the **neck,** and contains a central row of **neck canal cells.** When the egg is ready for fertilization, the neck canal cells disorganize and leave a passage down which the sperms swim when there is sufficient water.

THE SPOROPHYTE.—After fertilization the zygote (sporophyte) begins development inside the old archegonium, and always remains attached to the top of the female gametophyte. When mature it consists of a long stalk, **seta,** with an enlargement, **capsule,** at the upper end, in which the **spores** are borne.

SKETCH a female gametophyte bearing a mature sporophyte ; label all parts carefully. SKETCH the antheridium-bearing tip of a male gametophyte. DRAW an antheridium. SKETCH the archegonium-bearing tip of a female gametophyte. DRAW an archegonium

Summary of Bryophytes.

1. Bryophytes show very clearly alternation of generations, the alternation of a gamete-producing and a spore-producing plant in the complete life cycle. It may be illustrated : **Gametophyte** $<^{\text{sperms}}_{\text{eggs}}>$ (fertilization)——zygote——sporophyte——(reduction)——**spore**——**gametophyte,** and so on.

2. The antheridium and archegonium are multicellular, a new type of sex organ. The gamete-producing cells are surrounded by a single layer of sterile jacket cells.

3. All Bryophytes and all higher plants are heterogamous.

4. There is a tendency running thoughout the plant kingdom for the sporophyte to increase and the gametophyte to decrease in relative size and complexity. In Bryophytes, however, the gametophyte also shows increasing complexity, and the moss gametophyte is able to produce leaves. The moss sporophyte does not produce leaves. In Pteridophytes and Spermatophytes it is the sporophyte that produces leaves, and the gametophyte is a mere thallus, decreasing in size and complexity.

5. Bryophytes are an isolated group of plants. Nothing is known of their origin or their relation to Thallophytes, and they have not given rise to any of the higher plants. However, they probably illustrate stages through which the higher plants have passed in their evolution.

PTERIDOPHYTES.

Pteridophytes (fern plants) are mostly larger than Bryophytes. Alternation of generations is quite plain, but the gametophyte has become relatively small and simple, and the sporophyte large and complex. The sporophyte is completely differentiated into stem, leaves, and true roots; and vascular tissue (xylem and phloem) extend through every part to carry food and water. In Bryophytes the gametophyte is the dominant generation; in Pteridophytes (and Spermatophytes) it is the sporophyte that is dominant, and that shows such great variety of form and size.

There are several orders of Pteridophytes, both living and fossil. We shall notice only representatives of **Lycopodiales** and **Filicales**.

Lycopodiales

Lycopodiales (club mosses) are not included in the syllabus, but they furnish the key to a clear understanding of **vascular plants** (Pteridophytes and Spermatophytes). They are important because they show the simplest leafy sporophytes known. To be sure their must have been still simpler leafy sporophytes far back in the ancient history of plants, but we never have recognized any of their remains. Lycopodiales will be understood best by studying a few examples.

Lycopodium lucidulum is found in wet places in forests in cool temperate North America. Examine a specimen (sporophyte) and note that it consists of a branching **stem**, bearing a large number of small slender **leaves**, and with **roots** at the base. The spores are produced in small rounded organs, **sporangia**, borne in the axils of many of the leaves. A leaf which bears a sporangium is called a **sporophyll**. You will remember that in *Riccia* almost the entire sporophyte gives rise to spores; in moss it is only the capsule that produces

spores ; in *Lycopodium lucidulum* only a very small part of the sporophyte is devoted to the production of spores.

What shall not attempt to study the structure either of the sporophyte, or the gametophyte..

SKETCH a sporophyte to show the relation of stem, roots and leaves, and especially the sporangia. SKETCH a leaf with its sporangium, enlarged.

Lycopodium cernuum is another club moss growing on damp banks in the oriental tropics. The chief interest for us lies in the fact that the sporophylls are collected into dense groups at the ends of the branches. Such a dense group of sporophylls is termed a **strobilus.**

You will now realize that the entire plant of *Lycopodium lucidulum* is a sort of strobilus, and that the sam) leaves perform two entirely different functions, photosynthesis, and sporangium-bearing. In *Lycopodium cernuum* these two functions are separated ; the lower leaves have given up the sporangium-bearing function and have specialized in photosynthesis (i.e., are **foliage leaves**), while the upper leaves have given up most of their photosynthetic work and have specialized in the sporangium-bearing function (*i. e.*, are sporophylls), and are free to assume the special shape best suited to protect the sporangia. It is very important to understand the strobilus, because it is from such a structure that the flower of higher plants has been derived.

SKETCH a portion of the plant to show that the leaves are differentiated into foliage leaves and sporophylls, and that the sporophylls are collected into a dense terminal strobilus.

Selaginella. There are many species of *Selaginella,* widely distributed over the world. None are found locally, but two species grow in profusion in the Himalayas during the monsoon.

Examine a plant and note that it resembles *Lycopodium* in essential features. The sporophylls are in compact strobili at the ends of the branches, as in *Lycopodium cernuum.* The chief interest for us lies in the fact that there are *two kinds of sporangia* in the same strobilus. The smaller ones, **microsporangia,** borne in the axils of **microsporophylls,** produce many minute **microspores.** The larger ones, **megasporangia,** are borne in the axils of **megasporophylls** toward the base of the strobilus, and produce only four **megaspores.** These two kinds of spores produce different kinds of gametopyhtes. A plant producing two kinds of spores, is said to be **heterosporous.** Plants producing only one size of spores, as *Lycopodium,* are **homosporous.**

MALE GAMETOPHYTES. The microspore divides, inside the old spore wall, to form a minute few-celled **male gametophyte,** which produces a

small nnmber of sperms. There is no increase in size during the process of development.

FEMALE GAMETOPHYTE. The megaspore divides to form a **female gametophyte.** It grows somewhat during the process, and finally contains many cells. After a time it falls out of the sporangium. Continued growth bursts the old megaspore wall, and several archegonia are produced on the exposed portion. After fertilization occurs, the sporophyte embryos remain for some time embedded in the tissues of the gametophyte.

The female gametophyte, almost entirely enclosed within the old megaspore wall, is retained within the megasporangium during its early development; and after the eggs are fertilized, the young sporophytes are embedded in the tissues of the gametophyte for a time. These facts should be carefully understood, for heterospory, and the peculiar development of the gametopyhtes that goes with it, are the beginnings from which higher plants have evolved the seed habit.

SKETCH a portion of *Selaginella* to show stem, leaves, and strobili. SKETCH a strobilus to show the two kinds of sporophylls and sporangia. SKETCH a single microsporophyll with its microsporangium. SKETCH a single megasporophyll with its megasporangium. OUTLINE a microspore and megaspore enlarged, to show their relative sizes.

Summary of Lycopodiales.

1. The primitive *Lycopodiums* have the simplest leafy sporophytes known.

2. True vascular tissues are met for the first time in Lycopodiales.

3. In the simplest *Lyopodiums* the spores are borne in the axils of the leaves; the leaves therefore combine the two functions of photosynthesis and spore-production.

4. In the *Lycopodiums* we can trace a gradual specialization among the leaves, some retaining only the photosynthetic function, and others retaining only the spore-bearing function.

5. The sporophylls as they give up photosynthesis gradually become concentrated at the ends of branches to form strobili, which are the forerunners of flowers.

6. Lycopodiales pass from homospory to heterospory.

7. Heterospory separates the sexes into distinct male and female gametophytes; and the gametophytes always are small in heterosporous plants.

8. In *Selaginella* the megaspore is retained at least for a time in the megasporangium; the female gametophyte is more or less contained within the old megaspore wall; and the new sporophyte generation is embedded during its

early life in the female gametophyte. These tendencies look forward to seed production.

9. In all plants having alternation of generations, the gametophyte and sporophyte show differences, not only in appearance and behaviour, but also in the number of chromosomes in their nuclei. The nuclei of all the cells of the sporophyte contain 2N number of chromosomes, because each gamete contributes N chromosomes to the nucleus of the fertilized egg. The chromosome number is brought back to N during the two successive mitoses, reduction divisions, which result in the formation of the spores. The gametophyte, developing as it does from a single spore, has the N number of chromosomes in the nuclei of all its cells, and this number persists into the gametes. It follows that fertilization and reduction are very important events in the life cycle of a plant.

10. The life cycle of a homosporous plant may be illustrated: Sporophyte —— (reduction)—— **spore** — — **gametophyte** < **sperms** / **eggs** > (fertilization) —— sporophyte, and so on.

The life cycle of a heterosporous plant may be illustrated : Sporophyte—— (reduction) < **Miscrospore—— male gametophyte —— sperms** / **Megaspore——female gametophyte——eggs** > (fertilization) ——zygote——sporophyte, and so on.

With this rather extensive clearing of the Pteridophyte ground, we are ready to proceed to the study of the fern plant.

Filicales.

Filicales (ferns) include most of the Pteridophytes. Of the eight families of true ferns, Polypodiaceæ is much the largest, and includes the ferns we are to study. Ferns are found all over the world, and reach their greatest development, both in number and size, in tropical rainforests. Some are very small, only an inch or two high, while a few become tall trees resembling palms. Almost any polypod (belonging to the family Polypodiaceæ) fern would be suitable for study, and we shall use whatever material is available.

The Fern Sporophyte.

Examine a complete fern plant, such as *Nephrolepis exaltata*, commonly grown in pots on verandahs. Note that it consists of a short upright **stem** (or **rhizome**), bearing a number of large compound **leaves** (sometimes called **fronds**). Observe the long slender **runners**, resembling roots, extending out laterally from the stem ; they really are branches, and here and there produce buds which develop into new plants. The runners also function as main roots, and bear all the true **roots** of the plant. Note specially the **circinate** method of unrolling of the young leaves. SKETCH an entire plant to show the above features.

LEAF.—Examine a mature leaf in more detail. Each leaflet has a **midrib** running through the centre, from which small **veins** branch off and run almost to the margin. Most of the veins fork once or twice; this is **dichotomous venation**, and is characteristic of ferns. The margin of the leaflet is irregularly serrate.

SORUS.—On the under side of some leaves you will find brown dots, **sori** (sing. sorus), arranged in two rows on each leaflet. Each sorus is a group of **sporangia**, and is situated exactly over the end of a vein. A sorus is covered and protected by an umbrella-like flap of tissue, **indusium**. Examine a sorus under a hand lens or the binocular microscope, and see these features. **Sketch** a leaflet from the ventral side to show the exact shape, venation, and the sori. **Sketch** a single sorus in surface view enlarged.

Understand that a fern leaf is a sporophyll if it bears sporangia. The sporophylls are not collected into a strobilus.

SPORANGIUM.—Scrape off a sorus, tease it apart on a slide, and mount in 50% alcohol. Find a good sporangium, and examine under h. p. The sporangium is borne on a slender **stalk**, and is flattened, with thin side walls, and a single line of large thick-walled cells, **annulus**, extending most of the way round the edge. The small thin-walled cells, **stomium**, that make up the rest of the edge form a weak spot where the sporangium starts opening when the spores are mature. A sporangium produces a variable number of spores, up to a maximum of 64. **Draw** a single sporangium containing spores. **Draw** a single spore greatly enlarged, and indicate the magnification.

HOW THE SPORES ARE SCATTERED.—The ripe spores are scattered during dry weather by violent opening and closing of the sporangium. Scrape off a sorus from a leaf that has been boiled, and tease it apart thoroughly; mount in water and find good sporangia. Now add dilute glycerine at one side of the cover-glass, and draw it under by means of a piece of blotting paper at the other side. Watch carefully. No matter whether or not the sporangia have opened previously, you will see them slowly open; the annulus straightens out and finally curves backward; then suddenly it snaps back into the original position with such force that under natural conditions the spores would be thrown out to some distance.

The boiling fills the annulus cells with water. As this water is slowly removed by the glycerine by osmosis, it exerts sufficient cohesive force to draw the thick walls together, and the sporangium opens. Finally the elastic strain becomes so great that some of the water is vaporized inside the cells, and the annulus then jerks back into the closed position. WRITE NOTES on this experiment.

The Gametophyte.

DEVELOPMENT OF THE GAMETOPHYTE.—When a spore falls into a damp place it germinates. The protoplast enlarges, bursts the old spore wall, and grows out into a filament of cells, resembling a green alga. Then the end cells divide to form a flat thallus one cell thick, and later the cells in the midline divide to form a midrib several cells thick. The cells along the sides grow forward faster than the growing point, and the gametophyte becomes heart-shaped. Rhizoids from the ventral side attach it to the soil. While the gametophyte is young it produces antheridia. **Sketch** stages in the development of the gametophyte.

THE MATURE GAMETOPHYTE is a small heart-shaped bright-green liverwort-like thallus, growing flat on the damp ground. Examine a gametophyte from the ventral side under a microscope and see that the midline is several cells thick and bears numerous rhizoids, while the rest of the thallus is only one cell thick. The oldest part of the thallus is at the pointed end; the **growing point** is at the broad end at the bottom of the notch. The **antheridia** are scattered over the older parts, and by the time the gametophyte is mature most of them have shed their sperms. **Archegonia** are formed only when the gametophyte is mature. They are found on the ventral side, just back of the growing point, one row on each side of the midrib. **Sketch** a gametophyte from the ventral side to show all these features.

THE ANTHERIDIUM is much smaller and simpler than that of moss. It develops from a cell cut off usually from the ventral side of a thallus cell, and consists of a central mass of **sperm mother cells**, surrounded by a **jacket** of three curiously-shaped cells. Each mother cell gives rise to a single sperm. **Draw** an antheridium from a prepared section under the demonstration microscope.

THE ARCHEGONIUM has the same essential structure as that of moss, but is much simplified. The **venter** is embedded in the tissues of the gametophyte, and cannot easily be distinguished from the other cells of the thallus. Only the short **neck** projects from the surface. There are only two **neck canal cells**, and they are not separated by a wall. Between the neck canal cells and the egg is a **ventral canal cell**. **Draw** an archegonium from a prepared section under the demonstration microscope.

When the egg is ripe, the neck and ventral canal cells disorganize, leaving a passage down to the egg. Fertilization can occur only in the presence of liquid water in which the sperms can swim. This explains why ferns are found in damp places. When wet, the antheridia open, and the sperms swim out; some find their way to the archegonium, and pass down the neck canal. A single sperm fuses with the egg, and the fertilized egg is the first cell of a new sporophyte.

YOUNG SPOROPHYTE.—The fertilized egg divides first by a vertical wall, then by a horizontal wall. Of the four cells thus formed, the upper anterior gives rise to the **stem tip**, the lower anterior to the **first leaf**, the lower posterior to the **root tip**, and the upper posterior to the **foot**, an absorbing organ that remains embedded in the old archegonium and takes food material from the gametophyte. The root grows downward into the soil, and the stem grows upward through the notch and produces more leaves. The young sporophyte soon is able to make its own food and becomes independent of the gametophyte, which after a time dies. **Sketch** any available stage of a young sporophyte from a prepared section under the demonstration microscope. **Sketch** an independent young sporophyte with the gametophyte still attached. Make a **diagram** to illustrate the life cycle of the fern plant.

Structure of the Sporophyte.

STEM.—Cut a t. s. of the stem of almost any polypod fern (*Pteris aquilina* is not very good, because it is rather complicated), mount, and examine under l. p. You will see a number of circular patches of vascular tissue, **vascular bundles**, arranged in a ring in a uniform field of **fundamental tissue**. **Diagram** the t. s. of the stem.

VASCULAR BUNDLE —Stain the section with iodine or chlor-zinc-iodide, and examine a vascular bundle under h. p. The large thick-walled cells in the centre are **xylem**; the large clear cells on each side of the xylem are **phloem**. The small cells at each end of the xylem mass are the first to be differentiated in the young stem, and are called **protoxylem**; the larger xylem cells in the centre are **metaxylem**. Surrounding the entire bundle is a narrow layer of flattened cells, **endodermis**. The small cells, filled with starch and other materials, packed around and between the xylem and phloem are **parenchyma**. The parenchyma between the xylem cells is called **xylem parenchyma**; that between the phloem cells is **phloem parenchyma**; and the one or more layers outside the xylem and phloem, in contact with the endodermis, make up the **pericycle**. **Draw** the t. s. of a vascular bundle as carefully and accurately as you can.

Cut and stain a l. s. of the stem to see the structure and arrangement of the parts of the vascular bundle. In a well cut section passing through the middle of a bundle, you will see that the xylem cells are long, and that the walls are not uniformly thickened. The thickenings are in the shape of a spiral in the protoxylem, so these cells are called **spiral vessels**. The thickenings of the metaxylem are in the form of ladder-like parallel bars, so these cells are called **scalariform vessels**. The side walls of the phloem cells are perforated by tiny pores arranged in patches, **sieve plates**, from which the cells are called **sieve tubes**. The parenchyma cells are all short. **Sketch** a vascular bundle in l. s. **Draw** a

portion of a spiral vessel ; of a scalariform vessel ; of a sieve tube. **Draw** a few of the parenchyma cells to show their relation and contents.

Of what are the walls of the xylem cells composed ; the phloem cells ? What is the material stored in the parenchyma cells ? What is the function of the xylem ; phloem ; parenchyma ? WRITE NOTES.

Examine a fern stem from which the parenchyma has been removed, leaving only the vascular bundles. Observe that the bundles do not run straight through the stem, but anastomose to form a cylindrical network. Branches of the stem bundles, **leaf traces**, pass out into the petioles of the leaves. **Sketch** the vascular system of a fern stem.

GROWING POINT OF THE STEM.—Examine a prepared l. s. through the growing point of a fern stem. The stem develops from a single large **apical cell.** You will also see the growing points of young leaves a little way back from the apical cell. **Sketch.**

ROOT.—Cut and stain a t. s. of a fern root, or examine a prepared section. The structure of the root is thought to be very primitive, and is simpler than that of the stem. The xylem bundles are in a ring, with the protoxylem outermost Alternating with the xylem points, and in the same ring, are the phloem bundles. A layer of pericycle surrounds xylem and phloem. These structures make up what is known as the **stele**. Outside the stele is the broad **cortex**, of which the innermost cell layer is the endodermis. A stele with the xylem and phloem on alternate radii is said to be **radial** ; when the protoxylem is outermost, it is said to be **exarch**. The stele of the fern root is therefore **exarch radial. Diagram** the t. s. of a fern root.

GROWING POINT OF THE ROOT.—Examine a prepared section of a fern root tip. The tissues of the root arise from a single large **apical** cell, as in the stem. The root is protected as it pushes through the soil by a cap of cells, **root cap,** which also arises from the apical cell. **Sketch** a l. s. of a root tip.

LEAF.—Carefully tear off a piece of the lower epidermis, mount, and examine. Observe that it consists of large irregular cells fitting close together. Here and there are **stomas**, much smaller than the epidermal cells, made up of two kidney-shaped cells, **guard cells**, with a lens-shaped space between them. Note that all the cells of the epidermis contain chlorophasts. **Sketch** a few cells of the epidermis. **Draw** a stoma greatly enlarged.

Cut and examine a t. s. of a leaflet. On each side is a layer of epidermis. The central part is filled with chloroplast-containing cells, **mesophyll**, between which there are large **intercellular spaces.** These spaces form an irregular network of air passages, connecting with the outside air through the stomas. The

cut ends of vascular bundles will show here and there in the mesophyll. **Sketch** a portion of the section.

Ferns represent a specialized branch of the Pteridophytes. They are not in the main line of plant evolution, and certainly have not given rise to the seed plants. The origin of Spermatophytes must be sought much farther back among the primitive Pteridophytes.

SPERMATOPHYTES.

Spermatophytes (seed plants, Phanerogams). In Spermatophytes the sporophyte is the dominant and conspicuous generation, as in Pteridophytes, but the gametophyte generation is much smaller and is completely dependent (parasitic) on the sporophyte. The most important advance over Pteridophytes is in the formation of seeds. Practically all plants we are familar with are seed plants.

Spermatophytes are divided into two great groups: **Gymnosperms,** in which the seeds (megasporangia) are borne on the surface of the sporophylls, and **Angiosperms** (flowering plants), in which the seeds are borne in cavities in the sporophylls.

Gymnosperms.

Gymnosperms are not included in the syllabus, but it will be very helpful to make a brief study of the gametophyte generation, the method of producing the seeds, and the structure of the seed. There are no Gymnosperms native to the Plains, but there are a few cultivated specimens to be fonnd. In temperate regions Gymnosperms produce some of the most magnificent and valuable forests in the world. We shall study :

Pinus (pine). The pines are large trees. *Pinus longifolia* (chir) and *P. excelsa* (chil) are abundant in the Himalayas. The sporophylls are collected into dense compact strobili. Recall that among Pteridophytes, the simplest *Lycopodiums* have scattered sporophylls, and the most advanced have them collected into terminal strobili, and that all the sporophylls, sporangia, and spores are alike. In *Sellaginella* there are two kinds of sporophylls, sporangia, and spores; the small spores give rise to male gametophytes, and the large ones to female gametophytes. In *Pinus* also there are two kinds of sporophylls, and they are borne in separate strobili, but on the same tree.

Examine a branch bearing strobili of microsporophylls. Note that each microsporophyll consists of a small leaf with two microsporangia on the lower side. The microspores, and the male gametophytes that develop from them, are small. In seed plants the microspores and the male gametophytes that develop from them are called **pollen grains. Sketch** a strobilus of microsporophylls. **Sketch** a single microsporophyll. **Sketch** a male gametophyte from a prepared section under the demonstration microscope.

Examine a branch bearing strobili of megasporophylls. Each sporophyll bears two megarporangia on the upper surface. It will be necessary to understand clearly just what happens inside the megasporangium. A small number of megaspores is formed inside the young megasporangium, and only one of them succeeds in developing into a female gametophyte. The female gametophyte contains perhaps as many cells as the gametophyte of a fern, but it is not as much differentiated. It is *always* contained within and dependent on the megasporangium (sporophyte). When mature the female gametophyte produces a few very simple archegonia, consisting of a very large egg and a minute ventral canal cell; and a neck of four or more cells without neck canal cells. **Sketch** a strobilus of megasporophylls. **Sketch** a single megasporophyll to show the two megasporangia. **Sketch** a section through a mature megasporangium to show the female gametophyte within.

Throughout the lower plants the sperms swim to reach the eggs. Spermatophytes show a great change from this. The male gametophyte (pollen grain) is carried by wind or insects to the megasporophyll, where it continues growth. It puts out a **pollen tube** which carries the sperms down through the various intervening tissues to the egg. Two groups of living Gymnosperms still have sperms that swim a short distance to meet the egg, *after* they have been discharged from the end of the pollen tube, In *Pinus* the sperms do not swim at all.

After fertilization the fertilized egg divides to form a sporophyte embryo, which is contained within the tissues of the gametophyte all through the early development, and through the period the ripe seed remains dormant. It is only when the embryo begins to grow at the time of germination that it breaks out of the gametophyte, puts out roots and leaves, and becomes an independent plant.

Examine a ripe seed of *Pinus.* The hard outer covering, **seed coat,** is developed from the old megasporangium (sporophyte tissue); the oily white part inside is the **endosperm** (female gametophyte) ; the little **embryo** in the centre of the endosperm is the new gametophyte generation.

SKETCH a megasporangium in which the female gametophyte contains a sporophyte embryo. **Sketch** a l. s. of a seed.

WHAT IS A SEED ? We are now in position to define a seed. A seed is a reproductive body produced as a result of fertilization. It consists of a sporophyte embryo completely contained within the female gametophyte, which is completely contained within the old megaspore wall, which in turn is completely contained within the megasporangium (sporophyte). Thus there are *three distinct generations involved in a seed.* It becomes clear that *Selaginella* is not far from seed production. The seeds of Angiosperms differ in no essential feature from those of *Pinus. Pinus* will serve as a connecting link between Pteridophytes and

flowering plants, and will make clear a transition otherwise difficult to comprehend.

Angiosperms.

The Angiosperms are the flowering plants, and though they are easy to recognize, it is not easy to define what a flower is. The outstanding characters of the Angiosperms are (1) the flower, and (2) the megasporophyll completely surrounds and encloses the megasporangia.

There are about 130,000 species of flowering plants, and they are the most important plants in the vegetation over most of the earth. All the plants that make up the landscape of the Plains are Angiosperms.

The Sporophyte of Angiosperms.

The sporophyte is the generation with which we are familiar. General features of flowering plants have been studied already, while details of structure of the vegetative organs will be taken up later. We will trace through the life history.

THE FLOWER may be defined as a group of sporophylls (strobilus), usually associated with specialized leaves, the **perianth**. The *Selaginella* strobilus might be termed a flower, except it does not have a perianth; and there are many undoubted flowers that do not have a perianth.

NEW TERMS. The old terms applied long ago to the flower and its parts are still used; their relation to the terms we have been using is shown in the table:

strobilus (+ perianth)	=	flower
microsporophyll	=	stamen
microsporangium	=	loculus of the anther
microspore male gametophyte	} =	pollen grain
megasporophyll	=	carpel
megasporangium	=	ovule
megaspore	=	megaspore
female gametophyte	=	embryo sac

Examine a flower of *Gynandropsis pentaphylla* (hulhul), *Tribulus terrestris* (gokhrú), or other available simple flower, and study the following parts:

Perianth

1. **Calyx**, the outer cycle of green leaves (**sepals**) for protection of the flower bud.
2. **Corolla**, the next cycle of white or coloured leaves (**petals**) to render flower conspicuous.

Sporophylls or **essential organs**

3. **Stamens** or microsporophylls, the slender organs in the third cycle.

4. **Carpels** or megasporophylls, the central cycle, grown together in most kinds of flowers into a single organ (**pistil**).

SKETCH a flower and label with both sets of terms.

THE STAMEN consists of a slender **filament** or stalk, bearing an **anther**. An anther is really four microsporangia held together by the midrib (**connective**) of the sporophyll. **Sketch** the stamen of almost any flower, enlarged.

THE ANTHER.—Cut a t. s. of a large anther, and observe that it contains four cavities, **loculi** or microsporangia. The connective is traversed by the vascular bundle of the filament. The wall of each loculus is made up of epidermis and two or three other cell layers, and the cavity contains a mass of **spore mother cells** (or **pollen grains**, depending on the age of the anther), surrounded by a single layer of cells, **tapetum**, having a nutritive function. Often the cells beneath the epidermis become specially modified, and finally cause the rupture (**dehiscence**) of the mature anther. **Sketch** a t. s. of an anther. **Draw** a single loculus. **Sketch** a t. s. of an anther after dehiscence.

THE CARPEL (megasporophyll). The structure of a carpel may be illustrated by starting with a leaf-like sporophyll bearing the megasporangia along the margins; if now the leaf is rolled so that the edges meet and are turned inward, the resulting structure would be a fair representation of a carpel. Examine a carpel from a flower of *Sesbania grandiflora*, *Cassia siamea*, or other available legume with large flowers, and note that it consists of three parts : (1) **ovary**, the enlarged portion, containing the **ovules**, and tapering into (2) a **style**, a slender stalk bearing at its tip (3) the **stigmatic surface** (or **stigma**), on which the pollen grains are caught.

Dissect a nearly mature carpel of *Albizzia lebbek* (sirsá), *Dolichos lablab* (sem), or other large legume; examine also prepared sections of *Arisaema helleborifolium*. Observe that the ovary contains a cavity, **loculus**, into which the ovules project. Open the carpel so that the ovules lie on the outer edge ; the central rib will then represent the midrib of the megasporophyll. Cut a t. s. and a l. s. of the ovary and study the arrangement of all the parts. That portion of the ovary to which the ovules are attached is called **placenta**.

SKETCH a complete carpel. **Sketch** a nearly mature carpel opened into the form of a leaf, showing the ovules in their correct position. **Sketch** a t. s. and a l. s. of a carpel.

In most common plants the several carpels are united together into a single structure, called **pistil**. The edges of the carpels meet in various ways, but

always so that the ovules project into the resulting cavities. Cut a t. s. of the ovary of *Hibiscus esculentus* (bhindi), *Canna indica*, or whatever large ovary may be available, study, and SKETCH to show the relation of all the parts.

THE OVULE is really a megasporangium with the addition of one or two thin layers grown up over the outside. Examine a prepared section of the ovary of *Euphorbia pulcherrima*, *Canna indica*, *Lilium*, or *Arisaema helleborifolium*, and study the l. s. of an ovule. The central portion, **nucellus** or megasporangium, contains the **megaspope mother cell**, and later the four **megaspores** that develop from it. Two (one in some plants) **integuments** grow up from the base and entirely cover the nucellus except for a minute pore, **micropyle**, at the outer end. The basal portion of the ovule is the **chalaza**, and the stalk is called **funiculus**. SKETCH the l. s. of the ovule. *The ovule finally becomes a seed, and the ovary becomes a fruit.*

The Gametopytes of Angiosperms.

Flowering plants, also *Selaginella*, are heterosporous, hence the sexes are separated into two entirely distinct male and famale gametophytes. These gametophytes are very minute, consist of only a few cells, and develop within the tissues of the sporophyte. Their significance was not understood until cryptogams came to be carefully studied and understood.

THE MALE GAMETOPHYTE is the pollen grain. Examine as many prepared slides as time permits and trace the development of the pollen grain. The cells in the microsporangium (loculus of the anther) divide and finally give rise to the **miscrospore mother cells**. Each mother cell undergoes the two reduction divisions, forming four **microspores** (young pollen grains) each with the **N** number of chromosomes. A microspore is the first cell of a male gametophyte. The microspore forms a thick lignified wall, **exine**, outside the original thin cellulose wall, **intine**, and the nucleus divides to form a large **tube nucleus** and a small **generative nucleus**. The tube nucleus controls all the further activities of the pollen grain. The generative nucleus may or may not form a distinct cell about itself, and later divides to form two **sperms**. The pollen grains are ready to be shed at this stage.

Further development takes place on the stigmatic surface of the carpel. The pollen grains are transferred to the stigma either by wind or insects ; the process of transference is **pollination**, and has been studied already. The exine of pollen carried by wind is dry and smooth; that carried by insects is sticky, and is provided with various kinds of projections for attaching to insect visitors. There is a number of minute pores in the exine, through one of which the pollen tube grows out.

Upon the stigma the pollen grain puts out a **pollen tube**, which grows

down through the tissues of the style, into the loculus of the ovary, down the micropyle of an ovule, and through the end of the nucellus to the waiting egg within. In the meantime the generative nucleus has divided into two **male nuclei** or **sperms**. The male gametophyte is so greatly reduced in size and number of cells that there is no room for the formation of an antheridium.

DRAW a microspore mother cell. DRAW a tetrad of (four) microspores. SKETCH the surface view of several kinds of pollen grains. DRAW a mature pollen grain from a prepared section. DRAW a germinated pollen grain with its pollen tube.

THE FEMALE GAMETOPHYTE. A single **megaspore mother cell** develops near the tip of the nucellus. This cell undergoes reduction, forming a tetrad of four **megaspores** in a row. Each megaspore contains the **N** number of chromosomes, and is the first cell of a female gametophyte, but only the one nearest the chalaza actually develops, while the other three degenerate. The **functioning megaspore** enlarges and divides to form female gametophyte or **embryo sac.** The nucleus divides without wall formation into two, and these two into four, and the four into eight nuclei, four at each end of the sac. One nucleus from each end moves to the centre of the sac where they unite to form the **fusion nucleus.** The three nuclei remaining at the micropylar end organize into cells to form the **egg apparatus**, consisting of an **egg** cell, and two **synergids** or helper cells. The three nuclei remaining at the chalazal end are cut off by walls as **antipodal cells,** which are of no further importance. The embryo sac is now complete and the egg is ready for fertilization. All this development takes place within the wall of the old megaspore, embedded in the tissues of the nucellus. The female gametophyte has become so much reduced in size that there is nothing left of the archegonium but the egg. From prepared sections DRAW the end of a nucellus containing a megaspore mother cell. DRAW a functioning megaspore. DRAW a mature embryo sac (*Arisaema helleborifolium* is excellent.)

FERTILIZATION. The pollen tube that has been growing towards the ovules now penetrates to the egg and bursts, discharging the two sperm nuclei into the embryo sac. One male nucleus fertilizes the egg, which then develops into a new plant, the **sporophyte embryo**. The other male nucleus passes on to unite with the fusion nucleus to form the **primary endosperm nucleus** from which the endosperm is developed. Probably endosperm is to be thought of as a continued development of the female gametophyte. The functioning of both sperms in Angiosperms is called **double fertilization,** and is a fact of great importance that must be taken into account by plant breeders.

The Seed.

The seed develops from a fertilized ovule. The fertilized egg divides to form a filament of cells, the terminal cell of which gives rise to the embryo

proper. At first the embryo is merely a mass of cells, then gradually differentiates into : **caulicle**, a short stem bearing at one end the **radicle** or root tip, and at the other end the **plumule** or terminal bud, and on the sides the **cotyledons** or seed leaves, the first leaves of the plant, whose function is to provide food for the young plant.

While the embryo is developing, the primary endosperm nucleus divides repeatedly, filling the enlarging space of the embryo sac and surrounding the embryo with a tissue of cells, **endosperm**. In some seeds, the embryo uses the endosperm for food about as fast as it is formed, and the cotyledons become filled with stored food ; in others the endosperm persists as a definite tissue till the time of germination, when it is digested and absorbed by the cotyledons and used as food by the growing embryo. In any case the endosperm is a nutritive tissue.

Along with the developing embryo and endosperm, the integuments and the remains of the nucellus undergo certain changes, and become the **seed coats** of the mature seed ; their function is protection.

Understand that the sporophyte embryo is embedded in the female gametophyte (endosperm) within the old megaspore wall, and this in turn always remains within the megasporangium (nucellus, old sporophyte generation). This may be taken as the morphological definition of a seed. We shall find that from another point of view, a seed may be defined as a reproductive structure resulting from a fertilization, and capable of withstanding very severe conditions, of being transported over long distances, and of remaining alive for a long period of time.

Study the development of the seed from prepared sections of very young seeds of *Rumex acetosella* or *Fagopyrum* under the demonstration microscope. SKETCH.

Cut a l. s. through a nearly mature seed of *Albizzia lebbek* (sirsá) or *Arachis hypogea* (momphalí) and find the above parts. In these seeds the endosperm is absorbed by the growing embryo. SKETCH. Dissect a mature seed of *Ricinus communis* (reṉḍí) ; here the endosperm persists as a conspicuous oily tissue surrounding the embryo. Cut a l. s. also. SKETCH. Label all parts carefully.

The Fruit.

At the same time the ovules are developing into seeds, other parts of the flower are also stimulated to further development and become the fruit. Usually it is the ovary alone (either each separate carpel, or all the carpels joined together) that becomes the fruit, but there are a few plants where style, calyx, receptacle or even the inflorescence axis takes part in fruit formation. Examine the following fruits and determine what part of the flower they come from : *Crotalaria juncea* (sanai) ; *Andropogon sorghum* (jawár) ; *Gossypium sp.* (kapás plant) ; *Musa*

sapientum (kelá) ; *Citrus medica* (nimbú) ; and *Anona squamosa* (sharífa). Make SKETCHES of the external appearance and of appropriate sections to show the structure of these fruits.

The function of the fruit is partly to protect the growing seeds, but mainly to aid in scattering of the seeds when they are ripe. To accomplish this function, fruits show a great variety of form and structure. They have already been studied in connection with dissemination of the seed.

Germination.

The mature seed contains a little sporophyte embryo, in some cases surrounded by endosperm, and protected by the hard, partly water-proof seed coats. Usually the embryo has ceased growing and is in a dormant condition. Some seeds remain alive in this condition for 50 years ; others can remain alive only a few months or years. When the embryo begins to grow again after a period of rest, and pushes out of the seed coats to form a new plant, the process is called **germination.** Moisture, oxygen, and proper temperature are necessary for germination.

Plant some of the following seeds in the garden : *Cicer arietinum* (chaná) ; *Ricinus communis* (reṉḍí) ; *Luffa aegyptica* (ghíyá) and *Andropogon sorghum* (jawár) ; and from time to time observe and sketch the process of germination. Note what happens to each part of the embryo, to the endosperm, and to the seed coats. Understand the function of each part.

Plant seeds at various depths in a germination box or in the garden and observe the effect of depth of planting on germination. WRITE NOTES.

STRUCTURE OF THE VEGETATIVE PARTS OF THE FLOWERING PLANT.

The structure of the vegetative parts is surprisingly uniform throughout flowering plants. Almost any plant might be studied, but we shall select plants that show most clearly the various features we want to study.

The Stem.

Cut a t. s. of the internode of a young stem of *Ricinus communis* (reṉḍí), *Helianthus annuus* (súraj mukhí), *Xanthium strumarium* (chhoṭá dhatúra), or *Blumea sp.*, stain with iodine, and examine. The stem may be divided into three regions :

EPIDERMIS, a single layer of cells on the outside.

CORTEX, a broad ring of parenchymatous cells, the innermost of which, **endodermis**, contains starch grains, and,

STELE, all the tissues lying within the cortex. Near the outer edge of the stele is the ring of **vascular bundles**, consisting of **xylem** (toward the centre of the stem) and **phloem** (toward the periphery), with

a narrow band of meristematic cells, **cambium**, between them. The parenchyma in the centre of the stele is **pith**; that outside the vascular bundles, next the endodermis, is **pericycle**; and that between the vascular bundles, connecting pith and pericycle, is **medullary rays**. Make a DIAGRAM of the t. s. of the stem to show these features.

The cells of the stem are differentiated into a number of different kinds of tissues to enable it to perform its various functions. Cut sections and study the structure and distribution of the tissues performing the following functions:

1. TRANSPORTATION.—The xylem vessels carry water and the sieve tubes carry food materials in solution. The structure of these parts will be taken up in detail a little later. Water and food materials in solution can move very slowly by diffusion through parenchymatous tissue, but this is not be thought of a true transportation.

2. MECHANICAL SUPPORT.—In the young stem the **xylem** is the main supporting tissue. As the stem becomes older other mechanical support tissues are developed: **xylem parenchyma**, elongated cells with thick lignified walls; **sclerenchyma** (or hard bast), elongated pericycle cells with pointed ends and thick lignified walls, usually just outside the phloem, but sometimes including nearly all the pericycle; and in many kinds of plants, **collenchyma**, elongated parenchymatous cells, with the cellulose walls thickened at the corners, in several layers just beneath the epidermis.

3. PROTECTION.—The epidermis is the protective layer. The outer walls of the cells are thickened. Stain with Sudan III and see that the outer part, **cuticle**, of these thick walls is stained red, because it contains **cutin**. The cuticle renders the epidermis waterproof, and tends to keep out disease-producing organisms. The hairs found on many plants are outgrowths from the epidermal cells.

4. PHOTOSYNTHESIS.—Examine an unstained section and see that some of the outer cells of the cortex contain chloroplasts; these cells may be termed **chlorenchyma**, and they enable the stem to make considerable plant food.

5. FOOD STORAGE.—Starch is stored temporarily in ordinary stems. Stain a rather thick section with iodine and find the parts that store starch: sometimes the inner cells of the cortex, especially the endodermis; sometimes pith cells; usually the medullary rays; phloem parenchyma when it is present; and almost always xylem parenchyma.

Make a large DIAGRAM (4 inches across) of the stem section, and indicate by different colours the water transporting, food transporting, mechanical, protecting, photosynthetic, and food storage tissues.

THE VASCULAR BUNDLE.—Cut a t. s. of the stem, stain with iodine or chlor-

zinc-iodide, and study in more detail the parts of the vascular bundle. The cells in the xylem that appear empty are the xylem vessels. There are a few small **protoxylem** cells at the inner end, and the rest are **metaxylem**. Packed around and between these cells is **xylem parenchyma.** All xylem cells that are thick-walled are lignified. The phloem consists of large apparently-empty **sieve tubes**, each with a small **companion cell** beside it. In some stems there is **phloem parenchma,** filled with starch, between the sieve tubes. Phloem consists of **protophloem** on the outside, and **metaphloem** next the metaxylem, but they look alike and are not to be distinguished. Between phloem and xylem is a row of brick-shaped thin-walled meristematic cells, **cambium,** which later divide to add new cells to both xylem and phloem. DRAW in as much detail as time permits the vascular bundle you have been studying.

THE VASCULAR BUNDLE IN LONGITUDINAL SECTION.—Cut a thin median l. s. of the stem; this will will give you a radial l. s. of a vascular bundle. Stain and study. The protoxylem, differentiated while the stem is still elongating, is made up of spiral vessels with spiral thickenings. Metaxylem, formed after elongation has almost ceased, is made up of spiral vessels with close spiral thickenings, and a few of the last-formed vessels may be scalariform. Xylem parenchyma cells are elongated, with thick walls and square ends. The cambium cells are greatly elongated. The sieve plates of the sieve tubes are confined to the cross walls at the ends of the cells, and beside each sieve tube is a row of shorter parenchymatous companion cells. Phloem parenchyma, when present, is thin-walled and square-ended, and contains starch. SKETCH a l. s. of the vascular bundle.

SIEVE TUBES.—Cut both t. s. and l. s. of a stem of *Coccinia indica* (kundúrú) and study the very large sieve tubes. DRAW a t. s. of a sieve tube to show sieve plate and companion cell; DRAW the same in l. s.

PRIMARY GROWTH.—Vascular bundles that have the xylem toward the centre of the stem and the phloem toward the outside, *on the same radius*, are said to be **collateral**. When the protoxylem is the innermost portion of the xylem, it is **endarch.** The stem of the flowering plant therefore is **endarch collateral**. Bundles with cambium between the xylem and phloem are said to be **open**. Primary growth is the growth of the stem before the cambium has begun to add new xylem and phloem.

SECONDARY GROWTH.—There is no pause after primary growth is completed; secondary growth begins at once. Cut sections of older stems than were used for primary growth, and study the process of secondary growth. The cambium starts dividing and forms new cells on both sides. The cells on the inner side differentiate into **secondary xylem,** and those on the outer side into **secondary phloem**. Part of the secondary xylem becomes **pitted vessels**, in which

the thick side walls are perforated by pores of **pits**, and the end walls are removed to produce continuous tubes out of the rows of cells. Xylem parenchyma is the same as in metaxylem. Secondary phloem resembles primary phloem. Since secondary xylem and phloem are formed from repeated division of the cambium cells, they lie in radial rows. Soon after secondary growth begins in the bundles, a line of cells across each primary medually ray becomes meristematic, **interfascicular cambium**. This connects with the **fascicular cambium** of the vascular bundles to form a continuous **cambium ring**. Part of the cells cut off from the interfascicular cambium increase the length of the meduallary rays, but most are differentiated into xylem and phloem.

A few stems undergo very little secondary growth; while many continue for years and even centuries, forming the secondary xylem or **wood** that we use for so many purposes. Secondary phloem is formed at the same time, but it is soft and soon crushed and destroyed by the outward pressure of the hard xylem. As the stem increases in size, narrow **secondary medullary rays** are formed. Make DIAGRAMS to illustrate the process of secondary growth in the stem. Cut sections of an older stem of *Moringa pterygosperma* (sainjná) or *Bombax malabaricum* (semal) and make a DIAGRAM of a thick woody stem.

CORK.—As the epidermis cannot stretch much to keep pace with the growing stem, it soon cracks and loses its protecting power. Before this actually happens, a new protecting layer, cork, is formed in the cortex. An outer layer of cortex becomes meristematic, and is called **cork cambium**. The cells divide and form a number of layers of close-fitting brick-shaped cells, whose walls become impregnated with a waterproof substance, **suberin**; this is cork. With the development of cork, the stomas of the epidermis become useless, and to take their place passages called **lenticels** are formed in the cork. The cells of the lenticels are rounded, leaving intercellulor spaces through which gas exchange can take place. Lenticels appear as lighter coloured dots on the surface of young woody stems. Study and SKETCH cork and lenticels from sections of stems of sainjná or semal.

THE GROWING POINT OF THE STEM.—Examine a median l. s. of a stem tip of *Hydrilla verticillata* (a water plant), and study the growing point. It is made up of small polyhedral meristematic cells with dense protoplastic contents. There is no single apical cell. From the products of the meristematic cells the epidermis, cortex and stele are differentiated. Young leaves appear as small outgrowths of cortex and epidermis, and gradually enlarge to mature form and structure. In the axils of the young leaves, similar outgrowths of cortex and epidermis become lateral buds. The growing point is surrounded and protected by the developing leaves and the whole structure is called a **bud**. SKETCH a l. s. of a bud.

DICOTYLEDONS AND MONOCOTYLEDONS.—There are two great divisions of Angiosperms, **Dicotyledons and Monocotyledons**. We have been studying the stem of Dicotyledons. Dicotyledons differ from Monocotyledons in several important features, as shown in the following table :

	Dicotyledons	Monocotyledons
Flower parts	usually in 5's or 4's	usually in 3's
Number of cotyledons	two	one
Vascular bundles	in a ring	scattered
	possess cambium	do not have cambium
Secondary growth	takes place	no secondary growth
Leaves	larger veins form a network	larger veins run parallel
Venation	open	closed
Root system	taproot	fibrous
Roots contain	few (2-10) protoxylem points	many (20-150 protoylem points.

MONOCOTYLEDON STEM. The stucture is similar to the that of Dicotyledons. The vascular bundles are collaterial, and contain the same kind of vascular elements. They are not however arranged in the form of a ring, but are scattered through the stem. Often it is quite impossible to distinguish between cortex and stele, though in some, as *Cynodon dactylon* (dúb), the boundary shows clearly. Cut a t. s. of the stem of *Canna indica* and study, and DIAGRAM to show the arrangement of the parts.

MONOCOTYLEDON VASCULAR BUNDLE. Cut t. s. of a stem *Commelina bengalensis*, *Andropogon sorghum* (jawár), *Cynodon dactylon* (dúb), or other Monocotyledon, and study a single bundle. You will be able to recognize the small protoxylem cells, the few large metaxylem cells, a large amount of xylem parenchyma, and the phloem. The entire bundle is surrounded by a bundle sheath of thick-walld cells. There is no cambium, so secondary growth is impossible. Even such large stems as palms do not show any secondary growth. DRAW a t. s. of a Monocotyledon bundle.

The Root.

Roots are so uniform in structure that almost any kind may be studied. Cut and study a t.s. of a young aerial root of *Ficus bengalensis* (bargad) (Dicotyledon) and of a prop root *Andropogon sorghum* (jawár) (Monocotyledon). Note the three regions, epidermis, cortex, and stele. In the stele the vascular

elements are arranged in the form of a ring, but the xylem and phloem points are alternate with each other, i. e., are **radial** instead of collateral. The protoxylem is toward the outside (exarch) and the metaxylem toward the inside. The number of protoxylem points usually is small in Dicotyledons and large in Monocotyledons. The metaxylem may or may not differentiate clear across the centre of the root; if it does not, a pith is present. Between the vascular elements and the endodermis is pericycle. There is no cambium in the root during primary growth. DIAGRAM the t. s. of both kinds of roots.

SECONDARY GROWTH IN ROOTS. Cut sections of aerial roots of bargad and study secondary growth. Just within each point of phloem a layer of cells becomes meristematic to form the first cambium. This cambium begins to cut off secondary xylem on the side toward the stem centre, and secondary phloem on the primary phloem side, thus forming a true collateral bundle. Gradually the separate cambiums extend sidewise, *outside the protoxylem points*, to form a continuous cambium ring. Over the protoxylem points the cambium gives rise to primary medullary ray and not to secondary xylem. Secondary growth may continue till the root becomes very large, as in trees. An old root always may be distinguished by the fact that at the inner end of each medullary ray there is a patch of primary xylem, while there is no primary xylem at the inner end of the collateral bundles. There is no secondary growth in Monocotyledon roots. Make DIAGRAMS to show the process of secondary growth in the Dicotyledon root.

GROWING POINT OF THE ROOT. Cut and examine a median l. s. of a root tip of *Musa sapientum* (kelá). Like the stem tip, there is a group of meristematic cells, from which epidermis, cortex, and stele are developed. Unlike the stem tip, the end of the root is covered and protected by a cap of cells, **root cap**. Examine a prepared section of a root tip and see that just back of the root cap the cells are actively dividing, and still farther back the new cells are elongating. Growth includes both the production of new cells and elongation of these cells. Therefore the root tip is the region where all increase in length of the root takes place. The root cap, as well as the other regions, differentiates from the meristematic region. SKETCH the l. s. of a root tip to show these features.

REGIONS OF THE YOUNG ROOT. Examine the root of a seedling that has been grown on moist filter paper. The **region of cell division** and the **region of cell elongation** are white and quite smooth. Back of this, where elongation has ceased, is the **root hair region**, where many of the epidermal cells have produced slender tubular outgrowths, **root hairs**. The root hairs remain alive only a short time, then dry up, and older parts of the root are again bare. SKETCH a young root to show the regions.

ROOT HAIRS.—For the study of root hairs mount seedlings of *Papaver somniferum* (postá) or *Brassica juncea* (rai), and cut t. s. of the thick roots of seedlings of *Zea mays* (makái) or *Dolichos lablab*. Stain with iodine and examine under h. p. The root hair is actually a part of the epidermal cell, and contains large **vacuoles** and the nucleus of the cell. Root hairs function as little osmosis organs, and greatly increase the absorbing surface of the root. DRAW a portion of the epidermis with root hairs. Calculate the total surface of the root hairs you have been studying. How much do they increase the absorbing surface of the root?

The Leaf.

Leaves are developed specially for photosynthetic work, so they have a broad flat surface, blade, supported in proper position by a stalk, petiole. Often there is a pair of small blade-like structures, stipules, at the base of the petiole. Leaves can be found which show almost all imaginable variations from this general structure. Monocotyledon leaves usually have a **sheath** at the base surrounding the stem.

VENATION OF LEAVES.—The vascular bundles that leave the stele pass out across the cortex, traverse the petiole, and branch in the tissues of the blade; these branches are called veins, and their arrangement is an important character used in classifying plants. Dicotyledon leaves have either **pinnate venation**, in which the larger veins branch feather-wise from the **midrib**, or **palmate venation**, in which the larger veins radiate fan-like from the end of the petiole. Monocotyledons are characterized by **parallel venation**, in which the larger veins run practically parallel throughout the length of the blade. SKETCH a few examples of typical Dicotyledon and Monocotyledon leaves to show the parts and venation.

OPEN AND CLOSED VENATION.—Examine pieces of Dicotyledon and Monocotyledon leaves that have been made transparent by treatment with javelle water, and study the details of venation. In Dicotyledons the smaller veins anastomose to form an irregular network, with many of the smallest veins ending freely in the spaces. This is **open reticulate venation**. In Monocotyledons the smallest veins run transversely to connect the larger parallel veins, and none end freely. This is **closed parallel venation**. SKETCH both open and closed venation.

STRUCTURE OF THE LEAF.—Prepare a t. s. of a leaf of *Eugenia jambolana* (jámun), *Carissa carandas* (karaunda), *Dalbergia sissoo* (shísham), or other thick stiff leaf that may be cut easily, mount, and examine. Note that no matter how carefully the mounting is done the sections contain air; this is the air that fills the large intercellular spaces at all times. A short treatment with 50% alcohol will remove most of this air without dissolving out much of the chlorophyll.

Observe that the two surfaces of the leaf are covered with a layer of colourless **epidermis**. The lower epidermis, and sometimes the upper also, is perforated by minute passages, **stomas**, through which the air spaces are connected with the outside air. In the centre of the leaf is a mass of cells, **parenchyma** or **mesophyll**, containing chloroplasts. The mesophyll on the upper side consists of elongated cells at right angles to the surface, **palisade parenchyma**, while that on the lower side consists of irregular cells with larger air spaces between, **spongy parenchyma**. Here and there you will see the cut end of a vein, with xylem on the upper side and phloem below, and surrounded by a layer of colourless cells, bundle sheath. Thin soft leaves have less palisade parenchyma, while in thick leathery leaves, like *Calotropis procera* (ák), nearly all the mesophyll is of the palisade type. SKETCH a portion of the section you have been studying.

THE EPIDERMIS.—Tear off and mount a portion of the upper and the lower epidermis of almost any soft leaf, and study the arrangement of the epidermal cells and stomas. The latter consist of two kidney-shaped **guard cells**, with a lens-shaped space between them. Only the guard cells contain chloroplasts. By varying the amount of water they contain, the guard cells are able to change their shape, and open and close the aperture, and thus regulate to a considerable extent the loss of water from the leaf. SKETCH a portion of the epidermis to show the arrangement and relative number of stomas on the two leaf surfaces. Calculate the number of stomas per square centimeter (the diamater of the h. p. field is about 0·45 mm.). DRAW a single stoma greatly enlarged.

PHYSIOLOGY.

Physiology is the study of the processes by which the plant maintains its life and does its work. We have been studying structure, or how the plant is made; we shall now study function, or what the plant does. The experiments under "Functions of the parts of a plant" in the Preliminary Study should be reviewed, and repeated if necessary. The new experiments given here should be performed by the students themselves as far as possible, rather than by the instructor. WRITE CAREFUL NOTES on all the experiments, giving the purpose, methods, results, and conclusions to be drawn. Make sketches of apparatus, illustrate the results whenever possible, and write out the chemical reactions as completely as you can

Water in the Plant

RELATION OF ROOTS TO THE SOIL.—Plant seeds of *Brassica juncea* (rai) in fine sand. When the roots have developed root hairs, carefully wash the

plants out of the sand, and examine the roots under the microscope. Try to see how the roots are related to the particles of sand. How and why are the particles of sand held to the root. SKETCH and explain fully.

OSMOSIS.—The usual osmosis experiment has already been performed. Set up an osmosis apparatus, with coloured water in the thistle tube and a rather strong salt ($NaCl$) solution outside. What happens? Why?

Mount living *Spirogyra* or other green alga in water, and see that the protoplasm lies against the cell walls. Draw under the cover glass some 5-10% solution of potassium nitrate. The protoplasm quickly pulls away from the cell walls; this is **plasmolysis.** Explain. Now replace the potassium nitrate by distilled water, and see whether the protoplasts come back to the original position Explain fully.

Understand that root hairs take up water and dissolved salts from the soil by the process of osmosis. This water diffuses from the epidermal cells through the cortical cells to the xylem of the roots, and is carried upward to all parts of the plant.

ASCENT OF WATER IN THE STEM.—Cut off a leafy branch and place the cut end in water immediately. Lay another similar branch on the table beside it. Explain the result after an hour or two.

Cut off under water a soft stem bearing white flowers, and without exposing the cut end to the air, place in a vessel of water coloured red with eosin, and set where the wind will blow across it. Note the time it takes for the water (colour) to reach the flowers. Calculate the rate of ascent of the water in centimeters per second.

Cut a t. s. of the stem that has been in the eosin solution, and examine to see what part has carried the water. Show this in a diagram.

THE CAUSE OF ASCENT OF WATER through the plant is not fully known. Several causes probably work together, of which the most important are **root pressure** and **transpiration.**

ROOT PRESSURE.—Cut off a stem near the ground and attach a slender glass tube to the stump by means of rubber tubing. Tie the joints tightly to prevent leakage, and observe from day to day. Show clearly what is meant by root pressure, and how it is caused.

Grow a plant of *Tropaeolum* in a small pot. Water well and place under a bell jar to check water loss from the leaves. Note the small drops of water that form at the edges of the leaves. Here we see root pressure actually forcing water in the form of liquid out of the leaves. The same thing is seen frequently in many small plants on winter mornings. Do drops collect on the leaves of *Tropaeolum* when the plant is exposed to wind? Explain fully.

TRANSPIRATION is the loss of water in the form of gas from the leaves.

Recall the experiment of the bargad leaf covered with vaseline.

Soak filter paper in a 5% cobalt chloride solution. Carefully dry beside a gas flame, and observe the change in colour from pink to blue. Why is this? Breathe on a piece of the dry paper, and explain the change in colour. Now lay a piece of the dry cobalt paper on the upper surface of a fresh barged (or other) leaf and immediately cover with a piece of glass (to keep out any moisture form the air). Does the paper change colour? Why? Repeat the experiment on the lower surface of a leaf. Now what is the result? Explain full. The rapidity with which the cobalt paper changes colour may be taken as a measure of the rate of transpiration.

INTERCELLULAR SPACES IN THE LEAF.—Take a leaf with a rather long petiole. Fix the petiole with paraffin into a hole in the stopper of a bottle, so that the blade nearly touches the stopper. Half fill the bottle with water, and connect with an air pump by a glass tube that reaches to the bottom of the bottle. Turn the bottle upside down and exhaust the air. Note that bubbles of air issue from the end of the petiole as long as the pump is worked. Where does this air come from? Remember that the mesophyll of the leaf contains a network of air spaces, connecting to the outside air through the stomas.

POTOMETER EXPERIMENT.—Fix a fresh leafy branch of a plant into the potometer, and set the instrument up as directed (see RANGACHARI'S Botany, p. 180). A bubble of air introduced into the horizontal capillary tube moves toward the plant, showing that the plant is taking up water. This water passes upward to the leaves, where it is lost by transpiration. Measure the rate of movement of the bubble: in the quiet air of the laboratory; in the shade in wind; and in bright sunshine. How do these different conditions affect the rate of transpiration?

Water brought to the leaves evaporates from the moist surfaces of the mesophyll cells into the intercellular spaces, and finally diffuses through the stomas into the outside air. The mesophyll cells that have lost water take up more by osmosis from neighbouring cells, and these in turn take water from the xylem vessels of the veins. It is now generally believed that transpiration provides the necessary force for drawing water up through the xylem of the vascular bundles, and that the cohesion of water keeps the water columns from breaking. Root pressure can drive water up to the tops of small plants *when transpiration is slow*, but it cannot keep up with rapid transpiration, and is incapable of forcing water to the tops of lofty trees. Of the other supposed causes of ascent of water, atmospheric pressure is of little or no effect, "vital activity" of xylem cells explains nothing, while "pumping action" and "rythmic contraction" of cells are non-existent.

REGULATION OF TRANSPIRATION.—Stomas open when the guard cells are filled with water, and close when they have lost too much water by evaporation. By this means the plant is able to control transpiration to some extent. But remember that CO_2 cannot enter the leaf to be used in photosynthesis unless the stomas are open. So during very dry weather small plants with limited water-absorbing ability are in real danger. Examine the epidermis of two similar plants, one growing in dry air and the other under a bell jar, and see if you can detect any differences in the appearance of the stomas.

Many small plants solve the problem of excessive water loss by dropping some of their larger leaves, and thus decreasing the transpiring surface. Observe this in plants growing in dry places.

AMOUNT OF WATER IN PLANTS.—Cut branches of several different kinds of plants, and weigh as quickly as possible. Lay them in full sunlight to dry, and after they are thoroughly dry, weigh again. Calculate the percentage of water each originally contained.

FUNCTIONS OF WATER IN THE PLANT.—Water has many uses in the plant:

1. Protoplasm cannot remain alive without a certain amount of water.

2. While cells are still young and have elastic walls, water fills them and makes them turgid, enabling the soft parts of plants to stand stiff and erect.

3. Water is one of the raw materials used in photosynthesis.

4. It brings inorganic salts into the plant, and transports food materials in solution.

5. Stretching of the cellulose walls of young cells, due to turgidity, is the cause of elongation in plants.

6. And, especially on hot days, evaporation serves to cool the plant somewhat.

Withhold water from seedlings grown in sand, till they begin to feel dry. Does watering cause them to revive? Explain. Withhold water from similar plants till they wilt (lose their turgidity and droop down), then water, and see whether they are able to come back to the original position. How long does it take? Explain. Observe that small plants wilt during the hot days of the dry season, and recover again at night. Explain

Thoroughly dry a large leaf and place it in sunlight with the bulb of a thermometer under it. Place another thermometer under a fresh leaf, and note whether there is any difference in temperature under the two leaves. Explain.

The Food of Plants.

PHOTOSYNTHESIS.—Green plants are able to make their own food, while animals have to use food that has already been manufactured. Food manufacture, called **photosynthesis** (or sometimes **carbon assimilation**), is the combination of CO_2 and H_2O into a simple sugar, dextrose ($C_6H_{12}O_6$), by means of chlorophyll, in the presence of light. A large number of seedlings of *Ricinus communis* (rendi), *Cicer arietinum* (chana), and *Triticum vulgare* (gehún) should be kept on hand for the experiments on photosynthesis.

CHLOROPHYLL is a green pigment dissolved in the chloroplasts. Grind some soft green leaves in a mortar with fine quartz sand, and extract with alcohol. Examine and describe the alcoholic solution of chlorophyll.

CHLOROPHYLL IS FORMED ONLY IN LIGHT.—Grow seedlings in darkness. Note the colour. Now put a few of the plants in light (full sunlight is not necessary) and observe the slow change to green. How long does it take for chlorophyll to be formed? Explain fully. Plants without chlorophyll are often found under stones and in other dark places, and many plants have leaves with natural white spots or stripes.

CO_2 IN THE AIR.—Connect a bottle of lime water to an aspirator on the water tap, and draw air through the lime water over night. Does the result indicate that there is much CO_2 in the air? Compare with the amount of CO_2 in the breath, by blowing through a tube into lime water. There are about 3 parts of CO_2 in 10,000 of air. It enters the plant through the stomas, along with air, and diffuses through the intercellular spaces to all the cells of the mesophyll.

THE PROCESS OF PHOTOSYNTHESIS.—We can study the conditions under which photosynthesis takes place, and the products that are formed, but we shall not be able to follow the actual process of food synthesis. Indeed, the process by which CO_2 and H_2O are united, and the reactions involved, are not certainly known. It is generally believed that the first step is the union of the CO_2 with the water of the mesophyll cells to form carbonic acid

$$CO_2 + H_2O = H_2CO_3$$

The carbonic acid is then reduced to formaldehyde

$$H_2CO_3 = HCOH + O_2$$

which is immediately condensed into dextrose

$$6(HCOH) = C_6H_{12}O_6$$

Dextrose is formed faster than it can be carried away from the leaf, and the excess if further condensed into starch

$$n(C_6H_{12}O_6) = (C_6H_{10}O_5)n + n(H_2O)$$

which appears as minute grains in the chloroplasts soon after photosynthesis

begins. These reactions can all be combined into one, which will make the essential features of the process clearer:—

$$6CO_2 + 6H_2O = C_6H_{12}O_6 + 6O_2$$

It appears from this equation that amount of oxygen liberated is equal to the amount of carbon dioxide used.

DEXTROSE IN THE LEAF —Test a soft green leaf that has been exposed to sunshine, with Fehling's solution. Use only a small amount of the reagent, else the blue colour will hide the red of a positive reaction. What is the result ? Describe fully.

STARCH IN THE LEAF.—Treat a similar leaf with alcoholic iodine (ordinary iodine will not penetrate) and determine whether starch is present. Stain thin sections with iodine and look for minute starch grains in the chloroplasts. SKETCH. Explain the presence of starch.

CHLOROPHYLL IS NECESSARY FOR PHOTOSYNTHESIS.—Place in the light seedlings that have been grown in darkness. After an hour or two test the leaves for starch. Compare with the leaves of similar seedlings that have been growing in light. Also, apply the alcoholic iodine test to any leaves with white spots, and see whether there is a starch in the spots. What conclusions do you draw from these experiments ?

LIGHT IS NECESSARY FOR PHOTOSYNTHESIS.—Keep two green plants in darkness for two days to allow all the starch to be removed from the leaves. Does any starch remain in the leaves? Now place one of the plants in the light, and after and hour or two test both for starch. What is the result ? What conclusions do you draw ?

CO_2 IS NECESSARY FOR PHOTOSYNTHESIS. —Keep chana seedlings in darkness long enough that no starch remains in the leaves. Put a plant in a test tube with a little water to keep it moist, place the tube in a large bottle with KOH in the bottom, and stopper tightly. Prepare similarly another plant as a control, with water in the place of KOH, and set both bottles in the sunlight. After an hour or two test the two plants for starch. What is the result ? Explain fully. What conclusions do you draw from this experiment ?

OXYGEN IS LIBERATED DURING PHOTOSYNTHESIS.—Elaborate apparatus is necessary to prove that oxygen is liberated from a land plant during photosynthesis. Place fresh water plants, as *Potamogaton*, *Naias* or *Hydrilla*, under a large funnel in a vessel full of water. Invert a testtube filled with water over the stem of the funnel, and set the apparatus in sunshine. Photosynthesis will begin at once, and the gas liberated with collect in the testtube. When sufficient quantity of the gas has been collected, test it with a glowing splinter. What is the gas ? Where did the CO_2 for photosynthesis come from ? Explain fully.

AMOUNT OF CARBOHYDRATE FORMED DURING PHOTOSYNTHESIS.—Keep a large plant with large leaves in darkness till the leaves are free from starch. Punch out (with a leaf punch, cutting circles 1 sq. cm. in area) about 50 pieces of leaf, all from the same side of the leaves. Quickly put the samples in the glass tube provided, stopper, and weigh accurately (the tube should be weighed previously). Now put the plant in full sunshine, and after two hours cut an equal number of samples from the opposite side of the leaves, and weigh as before. Dry both samples in a dessicator, first at about 60°C. for a day or two, then at 110°C. till the weight becomes constant. Close the tubes and weigh again. Calculate the increase in weight per square meter of leaf per hour. Estimate the amount of carbohydrate the entire plant can make in an hour. Write up this experiment very carefully, and explain all the steps in detail.

The above experiment is known as "SACH'S dry weight method" of estimating the amount of carbahydrate formed by photosynthesis. There are several sources of error in it (can you point out some of them?), but it does very well to show that the weight of a plant increases as food is manufactured.

OTHER METHODS OF OBTAINING FOOD have been studied, under "parasites," in the Preliminary Study of Plants.

Digestion and Movement of Food.

Food materials can move through the plant only in solution. Wherever carbohydrates or fat or protein is stored, it must be turned into soluble form before it can be carried to the place where it is to be used. The process is called **digestion**, and is brought about by **enzymes** (organic catalytic agents) produced by the living protoplasm.

DIGESTION OF STARCH.—Examine under h. p. the starch of grains of *Hordeum vulgare* (jáo) that has been germinated for a week on moist filter paper. Note that the starch grains are partly dissolved (digested); this has been brought about by the enzyme **diastase.** Compare with starch grains from ungerminated grains. SKETCH.

Grind some of the grains in a mortar with water, and treat with Fehling's solution. What is the result? What is the origin of the sugar? Compare with ungerminated grains.

Apply the iodine test for starch to sections of the cotyledons of seedlings of *Dolichos lablab* of various ages. Can you trace any change in the amount of starch present? What has become of it? Where has it been taken, and what has it been used for?

SUGAR IN YOUNG GROWING STEMS.—Cut sections of young petioles and stems, and treat with Fehling's solution on a slide. Can you find any evidence of

reducing sugar? Where does it seem to be located? How do you explain its presence?

We shall not attempt to study the digestion of fats and proteins; the tests are different from those we have been using, and proper study would require too much time. The digestion of these food substances is essentially the same as that of starch, i. e., they are rendered soluble (broken up into smaller molecules) by the action of enzymes. It is believed that each different substance is digested by a special kind of enzyme.

Growth

Growth in size or length involves both cell division and enlargement of the new cells. The amount of cytoplasm also increases. For the making of new cytoplasm, many complicated and little-understood chemical processes are involved. The simple carbohydrates, and nitrogen from the soil nitrates are combined in some way to form protein, which is the basis of protoplasm. Cell division has already been studied.

CELL ENLARGEMENT.—Examine a prepared section of a root or stem tip. The cells at the tip are polyhedral, and completely filled with protoplasm. Then small vacuoles appear in the cytoplasm; they contain osmotically active substances, and take in water in such large quantities that the elastic cellulose walls are stretched. The vacuole itself becomes larger and larger. The cytoplasm also increases in amount, but not fast enough to keep the cell filled, and it becomes a thin membrane lining the cell walls. After a time elongation is checked by hardening of the cell walls, and the shape does not change afterwards. SKETCH stages in cell elongation.

MEASUREMENT OF ELONGATION.—Germinate seeds of *Zea mays* (makái) and *Dolichos lablab* on moist filter paper, and when the radicles are 3-4 cm. long, make lines 1 mm. apart with waterproof India ink on several of the radicles. Observe again next day, and note the place where elongation is taking place. Understand that this place corresponds with the region studied for cell elongation, and that the older parts of the root are not elongating at all. Young stems behave in exactly the same way. Explain fully.

HEAT GENERATED DURING RESPIRATION.—All living parts of plants (and animals as well) are oxidizing food materials to liberate the energy necessary to carry on the life processes. This is called **respiration**. Part of the energy appears in the form of heat. Respiration is of course greater in places where growth is rapid, as in germinating seeds, stem and root tips, and wherever cambium is active. Soak some seeds of *Pisum sativum* (baṛá mattar) and place in a bottle with enough water to keep them moist. Close the bottle with a stopper through which a thermometer reaches down among the seeds. Prepare

another bottle similarly, using seeds that have been boiled and cooled. Place both bottles in darkness. The next laboratory period note the temperature of the two batches of seeds. Is there any difference ? Explain. Care must be taken to keep the second bottle sterile, else bacteria working on the killed seeds may raise their temperature higher that that of the living seeds.

OXYGEN IS USED DURING RESPIRATION.—Place some soaked seeds of baṛá mattar in a small vessel, and invert a test tube over them in a vessel of mercury. Prepare another batch of boiled (and cooled) seeds in the same way. Observe from time to time. What is the result ? What do the germinating seeds take from the air in the tube ? Exactly what does the experiment show ? Explain fully.

Fill a small dish with a strong solution of pyrogallic acid, place in a vessel of mercury, and cover with a large test tube. After the pyrogallic acid solution has absorbed the oxygen in the tube (when the volume of air is reduced to about one-fifth of the original), push two or three well-soaked seeds of baṛá mattar under the edge of the tube and let them rise to the surface of the mercury. Do they germinate ? Why ? Explain fully. What does this experiment show ?

CO_2 IS LIBERATED DURING RESPIRATION. Prepare an apparatus as shown in RANGACHDRI'S Botany, p. 17. If possible, use an aspirator attached to the water tap, instead of an aspirator bottle and regulate the flow so that the air will come through in small bubbles. Observe from time to time. Change the last bottle of baryta water (or lime water) if necessary. Explain fully. The experiment may be run for a definite length of time, and the amount of CO_2 accurately calculated.

Inorganic substances necessary for growth. Make up the following "three-salt" nutrient solutions as directed by the instructor :

1.	Complete nutrient solution.	5.	Lacking NO_3
2.	Lacking K	6.	,, SO_4
3.	,, Mg	7.	,, PO_4
4.	,, Ca	8.	,, Fe

Germinate seeds of baṛá mattar on wet filter paper till the radicles are about 5 cm. long, then transfer the seedlings to bottles containing the above culture solutions (as illustrated in RANGACHARI'S Botany, p. 200). Change the solutions at least once a week, or better, twice a week. Observe the cultures from time to time. Describe and explain as fully as you can the effect of each of the culture solutions on the growth of the plants.

EFFECT OF AERATION OF THE ROOTS ON THE GROWTH OF PLANTS.—Prepare a water culture in full nutrient solution, as directed above, and arrange

so that a current of air in the form of very minute bubbles shall pass through it constantly. How does the growth of the plant compare with that in a similar but unaerated solution ?

Grow two cultures of baṛá mattar in good soil. Water one to excess, so that the water level remains near the surface of the soil. Water the other only occasionally, and arrange good drainage so that the soil will be aerated as the water runs down through it. Observe the growth of the two sets of plants. What conclusions do you draw ? How can the observed effects of aeration be realized in actual practice of cultivation ?

Secretion.

A SECRETION is a substance made by living cells, that is of further use at some other place in the plant. A substance that is of no further use—a waste substance—is called an **excretion.** Probably most of the living cells of the plant form secretions of some sort. Some of the most obvious secretions are: the enzymes that digest the endosperm of seeds; those that digest the cortex ahead of young roots; that are formed by *Rhizopus* for digesting the substratum; and the nectar that is produced in flowers.

NECTER SECRETION.—Examine carpellate flowers of *Coccinia indica* (kundúrú) or other Cucurbitaceae (lauki, kaddú, taroi), and flowers of *Thevetia nereiifolia* (kanail), and observe the liquid, **nectar**, at the bottom of the corolla tube. Taste it. The nectar is secreted by the cells of the yellowish ridge, **nectary,** around the pistil.

Examine prepared (or freshly cut) sections of the large yellow nectaries on the inflorescence of *Poinsettia pulcherrima* (lál patti). The large palisade-like cells bordering the cavity are the secreting cells. SKETCH.

We shall not attempt to study any other secretions.

Response to Stimuli.

One of the fundamental characteristics of living protoplasm is its ability to be affected by and to make some response to stimuli of various kinds. These responses are known as **tropisms.**

RESPONSE TO GRAVITY—GEOTROPISM.—Everyone knows that the stems of plants grow upward into the air, and that the roots grow downward into the soil. We shall now try to discover the causes.

Place a pot of small seedlings in a horizontal position, and keep in a dark place (to avoid the effects of light). Does any change in position of the stems take place during the laboratory period ? Observe a day or two later, and describe what has happened. Carefully dig up the plants and see what the roots have been doing. What is the cause of these changes in position ?

Germinate seeds of *Dolichos lablab* on moist filter paper till the radicles are 4-5 cm. long. Now pin the seeds in a moist chamber (so that the roots will not be injured by drying), with the roots pointing in all directions. Keep in a dark place. Examine after a few hours or the next laboratory period, and describe the change in position.

Place a pot of seedlings in a horizontal position on a klinostat (see RANGACHARI'S Botany, p. 223), and examine carefully the next period to see what has happened. Explain.

RESPONSE TO LIGHT—HELIOTROPISM.—Place seedlings where the light will strike them from one side only. Observe carefully any change in position of the stems. Explain.

Place a pot of similar seedlings on a klinostat in one-sided illumination. What is the result? Explain.

Pin seedlings with radicles 4-5 cm. long in a moist chamber and expose to one-sided illumination. How do the roots behave? Explain.

RESPONSE TO MOISTURE—HYDROTROPISM.—Stems show little or no response to moisture. Plant seeds in wet sawdust in a shallow wire tray; place it in an inclined position in darkness, and keep well watered. Observe the behaviour of the roots as they grow downward out of the tray into the dry air. Explain fully.

Fill a germination box (see RANGACHARI'S Botany p. 34) with wet sawdust, and place a strip of cloth down the middle against the glass, with the upper end dipping into a vessel of water; this arrangement will provide a continuous supply of water down the middle only of the culture. Plant a line of seeds against the glass, and from time to time observe the growth of the roots. How do you account for the direction they take? Explain fully.

RELATIVE IMPORTANCE OF GEOTROPISM, HELIOTROPISM, AND HYDROTROPISM.—In order to study the relative importance of these three tropisms, plant seeds of mattar in wet sawdust in a wire trough. Set at an angle of 45° with the table top, and with the light coming in through a window. Arrange a strip of cloth as a siphon to keep the culture well watered. Light and gravity will act on the stems, and all three stimuli will act on the roots. Observe the experiment from time to time, and explain the results as fully as you can. What conclusions do you draw?

RESPONSE TO MECHANICAL STIMULATION.—A few plants are able to move more or less in response to touch. Experiment with plants of *Mimosa pudica* or *Bi ophytum sensitivum* (both chúhiya múhiya), and describe their behaviour to touch stimuli.

Write a complete account of the response of plants to stimuli. Show as clearly as you can the value to the plant of each kind of response.

TAXONOMY OF FLOWERING PLANTS.

Taxonomy is the study of the arrangement of plants into a system of classification, to show their relationships. Among the flowering plants, relationship is revealed more clearly by the flowers than by any other parts; then come fruits, leaves, and finally stems and roots. Similarity of flower structure usually indicates close relationship. Plants which are essentially alike, as all baṛá mattar plants, are considered to belong to the same **species**; similar species are grouped into a **genus**; similar genera into a **family**; similar families into an **order**; and similar orders into a **class**. The complete classification of the mattar plants would then be:

Angiosperms
  Class Dicotyledons
    Order Rosales
      Family Leguminosae
        Genus *Pisum* (mattar)
          Species *sativum* (baṛá mattar)
            ,, *arvense* (chhoṭá mattar)

Family, genus, and species are the units most commonly made use of. The scientific name of a plant is made up of the genus and species names, the former written with a capital letter, e. g., *Pisum sativum.*

It is of course useful to know the scientific names of some of the more common plants, but the student must not imagine that the study of taxonomy is nothing more than the mere remembering of names and technical terms. Our aim will be (1) to understand how plants are classified, and the principal characters that are made use of; (2) to find out the characters that distinguish some of the large important families; and to study representative plants of these families; and (3) to become as familiar as we can with the local vegetation.

EVOLUTIONARY TENDENCIES IN FLOWERING PLANTS.—The great variety of floral structure can best be understood when studied in the light of certain evolutionary tendencies observed in flowering plants :—

(1) Primitive flowers are considered to have many parts in each cycle, all attached to the receptacle, and all free from each other. The number of parts then tends to decrease to 5 or 4 in Dicotyledons (5 sepals, 5 petals, 5 or 10 stamens, and 5 carpels) and to 3 in Monocotyledons (3 sepals, 3 petals, 3 or 6 stamens, and 3 carpels); but in higher forms the number of parts in a cycle, especially the stamens and carpels, may be reduced to 2 or even 1.

(2) There is a strong tendency for the parts of a cycle to grow together,

resulting in a **gamosepalous** calyx, **gamopetalous** corolla, **mono—**, **dia—**, or **polydelphous** stamens, and **syncarpous** carpels.

(3) Adjacent cycles also tend to become united together, especially the stamens to the corolla, when they are said to be **epipetalous**.

(4) There is a tendency to pass from hypogyny to epigyny, as an extension of the preceding tendency. In **hypogyny** all the parts are free and attached to the receptacle; in **perigyny** the lower portions of the calyx, corolla, and stamens are united together into a cup-like structure, surrounding the ovary but free from it; in **epigyny** all the four cycles are joined together, so that the parts seem to come from the top of the ovary, when the ovary is said to be **inferior.**

(5) Finally, there is some tendency for the flowers to become irregular.

STUDY OF IMPORTANT FAMILIES.—In studying the representative plants of the families, pay special attention to the progress they have made in the various evolutionary tendencies, for this is the very foundation of classification. Make a habit sketch of each plant, and sketches to show the important features of the flower. Usually a median l. s. of the flower shows more of the structure than any other view. In every case try to make such sketches as will show the structure most clearly.

Several families of flowering plants are important on the Plains, either because they contain valuable economic plants, or because they make up a large part of the natural vegetation. We shall study the following families :—

Dicotyledons

1. Urticaceae	5. Solanaceae
2. Cruciferae	6. Cucurbitaceae
3. Leguminosae	
4. Malvaceae	7. Compositae

Monocotyledons

8. Gramineae	9. Liliaceae

URTICACEAE includes the figs. Flower **diclinous** (stamens and carpels in separate flowers); perianth of few parts, not differentiated into calyx and corolla; stamens as many as the perianth lobes; and a single one-celled and one-ovuled carpel.

Study *Ficus bengalensis* (bargad), *F. religisoa* (pípal), *F. glomerata* (gúlar), and other figs. In all these, the flowers are crowded on the inner surface of a thick fleshy hollow inflorescence axis, the whole becoming a fruit. In *Artocarpus lakoocha* (barhal) and *A. integrifolia* (kaṭhal) the flowers are crowded on the outside of a thick fleshy axis.

CRUCIFERAE includes many valuable crop plants and vegetables. Four sepals, *four petals, usually appearing like a cross*; 6 stamens, two short and four long; and two united carpels forming a two-celled ovary, and ripening into a siliqua.

Study *Brassica juncea* (ráí), *B. campestris* (sarson) *B. napa* (gobhí), and *Raphanus sativus* (múlí).

LEGUMINOSAE is next to the largest family of flowering plants, and contains some of our most valuable food and forage plants. The distinguishing character of the family is the *single carpel, ripening into a legume.* There are 5 sepals; and usually 10 stamens. The family is divided into three sub-families:

Mimoseae, with small regular flowers grouped into heads; calyx and corolla tubular; and stamens usually many. Study *Acacia arabica* (babúl) and *Albizzia lebbek* (sirsa).

Caesalpineae, with large slightly-irregular flowers; sepals and petals free; and 10 (or fewer) free stamens. Study *Cassia siamea, C. fistula* (amaltás), and *Tamarindus indica* (imlí).

Papilioneae, with very irregular corollas; and usually diadelphous stamens in groups of 9 and 1. Study *Cicer arietinum* (chana), *Cajanus indicus* (arhar), *Pisum sativum* (bará mattar), *Dolichos lablab, Indigofera enneaphylla, Sesbania aegyptica* (jait), and other available species. Most of the Leguminosae belong to this sub-family.

MALVACEAE are characterized by *monodelphous stamens forming a tube about the style.* 5 united sepals; 5 united petals; many stamens, epipetalous; and several united carpels.

Study *Gossypium* sp. (kapás) plant), *Hibiscus esculentus* (bhindí), *Bombax malabaricum* (semal), and others that are available.

SOLANACEAE includes many valuable vegetables, and may be taken as representative of a large group of high grade Dicotyledons. 5 united sepals; 5 united petals; 5 stamens; and 2 united carpels, with 2 loculi in the ovary, and many small seeds on large axile placentae.

Study *Solanum tuberosum* (álú), *S. nigrum* (makoí), *Capsicum* sp. (lál mirch), *Withania somifera* (asghand), and *Datura* sp. (dhatúra).

CUCURBITACEAE, a family producing edible fruits. Known by the *slender tendril-climbing stems, and the diclinous flowers.* 5 united sepals; 5 united petals; carpellate flowers epigynous; 3 monodelphous stamens; and 3 carpels; fruit a pepo (berry).

Study *Trichosanthes anguina* (chichinda) *Citrullus vulgaris* (tarbúza), *Lagenaria vulgaris* (laukí), or other available species. Nearly all of the local species are cultivated.

COMPOSITAE contains very few useful plants, but it is the largest family of flowering plants (with nearly 15,000 species), it is the most advanced family of angiosperms, and Compositae are abundant everywhere. The family is known by the *small flowers crowded into flower-like heads*. Each little flower is epigynous ; calyx reduced to hairs (**pappus**), or scales, or absent ; 5 or 4 united petals often very irregular (**ligulate**) ; 5 syngenesious epipetalous stamens ; and 2 united carpels, with a single ovule in the ovary ; fruit an achene, with the pappus persistent on the upper and for wind dissemination. The entire head of flowers is surrounded by an **involucre** of bract-like leaves, resembling a calyx.

Study *Helianthus annuus* (súraj mukhí), *Tridax procumbens*, *Carthamus tinctorius*, (kusum) *Volutarella divaricata*, *Launea asplenifolia*, and any others available.

GRAMINEAE, a large family, and the most useful to man, because it provides the most widely used food grains (gehún, makái, cháwal, etc.), and the grasses for grazing and fodder (jawár, bájara, etc.). Grasses are recognized by the *two-ranked leaves, with the bases sheathing the stem*, and the floral parts scale-like, called **glumes**. The flowers are arranged in little **spikelets**, with two **sterile glumes** at the base. Each separate flower is subtended by a **fertile glume**, and the floral envelope is reduced to a single scale, **palea**, and 2 small rounded bodies, **lodicules**, the swelling of which pries the glumes apart and opens the flowers ; 3 stamens ; and 1 carpel, with a single ovule, and a large two-branched feathery stigma. The ovary ripens into a grain.

Study *Triticum vulgare* (gehún), *Avena sativa* (jai), and *Pennisetum typhoideum* (bájara). Most grass flowers are too small to be studied easily. Observe the general characters of as many grasses as you can, and study the importance of the grasses.

LILIACEAE may be taken as typical of Monocotyledons. Flowers hypogynous ; perianth of 6 petal-like segments ; 6 stamens ; and 3 united carpels.

Study *Gloriosa superba*, *Asphodelus tenuifolius*, *Asparagus* sp., and *Allium cepa* (piyáz).

ECOLOGY.

Ecology is the study of the relation of plants to their environment. The environment is made up not only of climate and soil, but also of other plants, and of animals, including man. In the Preliminary Study of Plants, we have already considered the effect of the most important factor of the environment, i.e., water, and on the basis of their response to water supply, we have divided plants into hygrophytes, mesophytes, and xerophytes. This phase of ecology will not be further studied.

Thus far in the course we have been considering plants merely as individuals. But plants do not live by themselves; different species constantly are found associated together, in various ways, depending on the particular combination of environment factors. They live together in a way to be compared with human society. Throughout the following studies write full accounts of all your observations, and try to draw conclusions from what you observe.

FACTORS OF THE ENVIRONMENT.—The many different components or factors of the environment may the gathered into three groups: **climatic factors**; **soil factors**; and **biotic factors.** We shall notice each of these groups in some detail.

CLIMATIC FACTORS include all the things that make up what we call climate—rainfall, sunshine, temperature, humidity, and wind. From facts supplied by the instructor, make as complete charts as you can to illustrate the main features of the climate of Allahabad. Try to understand how each of these factors affects the vegetation.

SOIL FACTORS include the nature of the soil, topography, and the amount of water in the soil. Soils may be rocky, clay, or sandy; topography may be level, rolling, cut up by ravines, or mountainous. The amount of water in the soil depends on rainfall, drainage, texture of the soil, and to a very real extent on the proportion of this water that plants are able to make use of. Describe the soil factors of the Upper Gangetic Plain, and show as completely as you can how each of them affects the vegetation.

BIOTIC FACTORS include all living organisms and the products and effects of living organisms that are in any way associated with plants. The most important of the biotic factors are the micro-organisms in the soil, earthworms (kechua), white ants (dimak), insects, man, the domestic animals associated with man, and plants themselves and their remains. We shall a little later study the effects of man and his animals, and omit the other biotic factors. Make as detailed a list as you can of the biotic factors in the Gangetic Plain.

TYPES OF CLIMAX VEGETATION.—The general features of the vegetation are determined by climate. Soil and biotic factors produce only local modifications. From extensive studies of the vegetation of various parts of the world it has been found that vegetation tends to pass through changes in composition, till finally a stage is reached where the composition no longer changes; in this last stage, as fast as the old plants die their places are taken by other plants of the same species, and we say that the vegetation has reached the **climax**. There are three great types of climax vegetation: **forest, grassland,** and **desert.** Colour a small outline map of India to show the distribution of these three types of vegetation. Use green for forests, yellow for grassland, and brown for deserts.

PLANT SUCCESSION.—Everyone must have observed that the vegetation is not the same everywhere, but that different groups of plants are to be found in ponds, along river banks, in cultivated fields, or wherever conditions vary a little from the average. But these groups are not permanent. Plants decay and add organic matter to the soil, which can then hold more water; they decrease evaporation of water from the soil by their shade and by breaking the force of the wind. In a word, they create conditions which make it possible for a new set of plants to become established in the area, and finally the old set of plants is more or less completely driven out. A succession of such changes takes place, till at last plants belonging to the climax type become established. The process is called **plant succession.** Of course we can read about plant succession (see DUDGEON, WINFIELD. A contribution to the ecology of the Upper Gangetic Plain. Journal of Indian Botany, Vol. I, May, 1920), but it must be observed to be clearly understood. We shall study plant succession then in a series of field trips to places where the various stages in the process can be most easily observed. We shall attempt to trace succession from the earliest stages, found in large bodies of water, to the climax. We shall recognize the following stages:—

1. Free-floating submersed aquatic stage.
2. Attached submersed aquatic stage.
3. Attached emersed aquatic stage.
4. Wet meadow stage.
5. Dry meadow stage.
6. Thorn scrub stage.
7. Forest stages, terminating in the monsoon deciduous climax forest.

1. FREE-FLOATING SUBMERSED AQUATIC STAGE.—This is the first of the pioneer stages, in which the plants are found floating freely in the water at all depths. The principal plants are green algae; *Spirogyra* spp., relatives of *Spirogyra*, *Cladophora*, and *Oedogonium* spp. The plants occur in great abundance, and their remains accumulate as soil at the bottom, and gradually raise the level of the soil. In the course of a long time, if nothing interferes, the water becomes shallow enough for the appearance of other plants that root in the soil.

2. ATTACHED SUBMERSED AQUATIC STAGE.—A new group of plants gradually gains a foothold, all rooted in the soil at the bottom, and growing completely under water. *Potamogeton crispus* can grow in water as deep as 10 feet, but most of the plants of this stage are found in shallower water. The most important plants are *Chara*, *Potamogeton* spp., *Naias* spp., *Vallisneria spiralis*, and *Hydrilla*

verticillata. These plants also produce enormous amount of vegetation, and their remains still further raise the soil level.

3. ATTACHED EMERSED AQUATIC STAGE.—Conditions are now such that other plants, rooted in the mud but with their tops above the surface of the water, can come in. The most important plants of this stage are *Eleocharis plantaginea*, *Nymphaea lotus* (kamal), *Scirpus maritimus*, *Marsilia guadrifolia* (a water fern), and in very shallow water, *Panicum paspaloides* and *Ipomaea reptans*. *Lemna minor*, *Wolffia arrhiza* and *Azolla pinnata* (another water fern), floating plants that often completely cover the surface of the water, also appear to belong to this stage. Remains of these plants further raise the soil level, finally bringing it so near the surface of the water that land plants can gain a foothold.

4. WET MEADOW STAGE. The soil surface is now nearly or quite above the water. The most important plants are *Scirpus maritimus*, *Scirpus quinquefarius*, *Fimbristylis diphylla*, and *Cynodon dactylon* (dūb).

Where the wet soil area shifts, as it does at the edges of shallow ponds and along river banks, being entirely under water part of the year, and very dry during the dry season, the plants found are not those of the typical wet meadow, but annuals. Many species are found, the most common being *Polygonum plebejum*, *Potentilla supina*, *Juncellus pygmaeus*, and *Ranunculus sceleratus*.

5. DRY MEADOW STAGE.—Finally, after a long time, the soil level is raised high enough that it remains more or less dry during most of the year, and another set of plants gradually occupies the area. The dry meadow stage is dominated by grasses, *Andropogon annulatus*, *A. intermedius*, *Eragrostis tenella*, *and Elusine aegyptica*. Little Leguminosea, especially *Indigofera enneaphylla*, and two undershrubs, *Calotropis procera* (ák) and *Tephrosia purpurea*, are abundant. During the dry season a number of other very interesting little xerophytic perennials flourish and bloom.

6. THORN SCRUB STAGE.—In the protection afforded by the grasses of the the dry meadow stage, woody plants can spring up. This represents the early stages of the forest, such as found all over the hills to the south. Most of the plants are thorny, and so are able to resist grazing animals. The principal species are *Acacia arabia* (babúl), *Zizyphus jujuba* (ber), *Butea frondosa* (ḍhák) *Capparis sepiaria*, *Justicia adhatoda* (bakas), *Streblus asper*, and *Flacourtia sepiaria*.

A large part of the Plains is in the dry meadow stage, not because this is the climax, but because of the activity of man and his domestic animals. Here and there we find patches of thorn scrub, representing the most advanced stage that can develop in competition with man. If the influence of man could be removed, the thorn scrub would afford protection in which other trees could develop.

7. FOREST STAGES, LEADING TO THE MONSOON DECIDUOUS CLIMAX FOREST.—Where there is less human interference, as in the hilly regions to the south of the Gangetic Plain, a forest develops as the end or climax of the long process of plant succession. It is not necessary to name the trees of this forest, as we shall not be able to study them. *Tectona grandis* (ságun) and *Terminalia tomentosa* (sain) are the dominant trees when climax is finally reached. There is every reason to believe that in times long past the Gangetic Plain was forested, and that if the pressure of man could be removed, forest trees would gradually invade the area, and it would again become forested.

Study plant succession as it is illustrated various places about Allahabad, and write as complete an account of it as you can.

REVEGETATION OF AN AREA THAT HAS BEEN CULTIVATED.—Cultivation is the only activity of man that *completely* destroys (or at least it should completely destroy) the natural wild vegetation. Yet in every cultivated field wild plants are found growing along with the cultivated plants. Because these plants are growing where they are not wanted, they are called **weeds**. Study the weeds of cultivated fields, and try to find out why it is that they are so hard to destroy. How do they live from year to year ? How do they migrate from one place to another ? Study other areas that have been cultivated and are now returning to their original state. Can you find any succession here ?

EFFECT OF MAN ON THE VEGETATION.—The effect of man is nearly always to destroy the natural vegetation. Man and his animals interfere with every stage in the succession, mainly by cultivation, grazing, and cutting for food and fuel. While the vegetation is tending to develop through the various stages of the succession to the forest climax, the activities of man are tending to destroy it. The result is a very real balance between man and the vegetation. Nowhere has the vegetation of the Plains been able to progress beyond the thorn scrub stage, and most of the Plains is in the dry meadow stage, and probably in many small areas succession is entirely prevented. A larger human and animal population would (under present conditions) check succession at a still earlier stage, and would reduce much of the area to a waste of worthless vegetation ; while a smaller population would allow the vegetation to develop to a still higher stage.

Visit and study various areas, and try to find out what the effect of man on the vegetation really is. What natural plants are destroyed by his various activities ? Why ? What plants are able to persist ? Why ? What new plants, if any, come in ? Why ? What plants, if any, does man substitute for the ones he destroys ? Think out these problems, and try to find out the nature and extent of the effect of man on the vegetation.

EFFECT OF OVER-GRAZING.—When the grazing animals are too numerous,

they tend to destroy the useful perennial plants of the dry meadow, and their place is taken by an almost worthless annual grass, *Aristida adscenscionis.* Examine an area that has been over-grazed, and describe the condition of the vegetation as completely as you can. What steps may be taken to improve such an area ?

CONSTRUCTIVE EFFORTS OF MAN.—Does man ever make efforts to improve the vegetation ? Think of parks, planted crops, fruit orchards, protected military and dairy grass farms, and afforestation projects. Here we have man putting new vegetation in the place of old. Will the results be permanent ? What will happen when such projects are no longer cared for ? Why ? In other words, are any of the efforts of man really permanent improvements in the vegetation ? Along what lines should we undertake to improve the natural vegetation ? What benefits would come from real permanent improvement ?

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